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STORABLE SPACE TUG SYSTEMS STUDY

DATA DUMP

VOL. 6, OPERATIONS, PART I, SECT. 3

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GRUMMAN

VOLUME 6

PART I

SECTION 3

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6.4 ORBITAL OPERATION COSTS

The Work Breakdown Structure and the data requirements provided by NASA have been used to categorize the Orbital Operations Costs. Existing and postulated Ground Rules and assumptions are listed to provide a framework for estimating costs. A bottoms up estimate is contained in this paragraph for both manpower and software. Mission complexity of different tug configuration has been factored into the projected costs. Finally, estimates of mission related hardware costs are presented to complete the cost estimate.

6.4.1 Work Breakdown Structure

Tasks detailed below have been extracted verbatum from the NASA Space Tug Work Breakdown Structure (Ref. 1 and 2).

6.4.1.1 Flight Operations Control (NASA) WBS 320-07-04

This element includes all ground based equipment required to support Tug flight operations at sites, such as tracking stations and flight operations control center. This element includes the design, fabrication, integration, maintenance, software and qualification of the GSE associated with ground control during Tug flight operations.

6.4.1.1.1 Hardware - WBS 320-07-04-01

This element includes the design, development, test, and production of such hardware items as consoles, distributors, harnesses, tools, interfaces, computer, electronics, handling and servicing equipment, simulators, and test equipment that make up the hard pieces of the GSE.

6.4.1.1.2 Site Activation - WBS 320-07-04-02

This element includes the site installation, integration and checkout of the ground support equipment to the attainment of systems compatibility and operational readiness. The facility activation is not included here.

6.4.1.1.3 Maintenance - WBS 320-07-04-03

This element consists of that maintenance and repair effort associated with the GSE to maintain its operational readiness condition. Facility maintenance is not included here.

6.4.1.1.4 Software WBS 320-07-04-04

This element provides for the services and material to provide computer programming required in the development, test, validation and operation of all Tug GSE software systems.

6.4.1.2 Flight Operations Control DOD WBS 320-07-05

Same as 6.4.1.1

6.4.1.3 Flight Test Operations WBS 320-08-04

This element includes dedicated vehicle test flights and associated activities only. A dedicated test flight is a vehicle flight for test purposes and does not carry an operational payload. It includes all activities that support such test flight programs from the planning to launch, actual flight and return. All Tug launch support, operations support (i.e., countdown, tracking, etc.) data analysis and evaluation are included. Propellants and gasses are also included. Excluded are those flights that carry an operational payload. These are to be included under the appropriate operational elements even though the flight may, as a secondary purpose, serve as a Tug vehicle test flight.

6.4.1.4 Flight Operations, NASA WBS 320-11

This element includes the flight operations effort to support activities directly related to the Tug Mission. These activities include mission planning, flight control, flight evaluation and flight software.

6.4.1.4.1 Mission Planning WBS 320-11-01

This element provides the trajectory, timeline, and consumables reporting required to plan mission profiles. In addition, it includes planning launch schedules and providing contingency profiles and policies.

6.4.1.4.2 Flight Control WBS 320-11-02

This element consists of analysis of Tug peculiar flight control requirements, i.e., ground commands, flight control measurements, ground computer calculations and operations for attitude pointing, power management, data dump and inflight Tug system and payload analysis. It includes preflight development of flight operational data books, interface diagrams, and planning for operations and resolution of in-flight anomalies.

6.4.1.4.3 Flight Evaluation WBS 320-11-03

This element provides for post flight analysis of data and recommendations for corrections/modifications prior to the next flight.

6.4.1.4.4 Flight Support Software WBS 320-11-04

This element provides for the control of mission-related software changes and operational software required to evaluate mission success.

6.4.1.4.5 Flight Operations, DOD WBS 320-12

Same as 6.4,1.4

6.4.2 Ground Rules

6.4.2.1 ETR will be available for Shuttle/Tug launches 12/79 and WTR will not be available before 1983.

6.4.2.2 NASA and DOD will each have mission requirements which require the use of both operational launch sites.

6.4.2.3 The AF will be the executive agent and mission operating agency for the DOD and all DOD users.

6.4.2.4 The NASA will be the executive agent and mission operating agency for all users other than the DOD.

6.4.2.5 Operational management control of DOD missions will be exercised from a DOD Operations Management Center (OMC) colocated with the STC at Sunnyvale and utilizing the AFSCF network.

6.4.2.6 Operational management control of NASA missions will be exercised from a NASA Operations Management Center (OMC) Houston and utilizing the facilities of the STDN (includes TDRS).

6.4.2.7 The combined facilities of both NASA and DOD will be available to resolve emergency situations should they arise.

6.4.2.8 NASA will be the launch agency at KSC.

6.4.2.9 USAF will be the launch agency at VAFB.

6.4.2.10 Vehicle operations management control will be assumed by the operating agency at holddown release regardless of the launch site.

6.4.2.11 Three or more orbiters and Tugs will be assigned KSC for the common use of NASA and DOD during the operational phase.

6.4.2.12 Two or more orbiters and Tugs will be assigned VAFB for the common use of NASA and DOD during the operational phase.

6.4.2.13 Orbiters will be scheduled for use at each launch site on a national priority basis.

6.4.2.14 Orbiters may be exchanged between launch sites.

6.4.2.15 Each operating agency will be responsible for the planning of its own missions.

6.4.2.16 NASA will maintain a common mission design data base to be used by both operating agencies.

6.4.2.17 Mission design and mission planning capabilities of both operating agencies will be compatible in the following areas:

(a) Crew training and procedures

(b) Handling of contingency situations.

(c) Rescue mission design for rescue of a crew in a disabled orbiter.

(d) The on-board software will be the same for all vehicles with the exception of some mission peculiar subroutines.

(e) Operating Management Centers (OMC's) mission simulation facilities, and Launch Control Centers (LCC's) must be compatible with on-board software.

6.4.2.18 The DOD may utilize NASA-developed software in their OMC. DOD unique software, if required, will be developed and provided by the DOD.

6.4.2.19 The DOD may utilize the extensive facilities of NASA OMC to assist in resolving contingency situations should they arise.

6.4.2.20 DOD payloads will be processed in a DOD controlled facility at both VAFB and KSC.

6.4.2.21 NASA payloads will be processed in a NASA controlled facility at both VAFB and KSC.

6.4.2.22 A DOD Shuttle system simulator will be located at VAFB for the training of DOD personnel. This simulator will be available for closed loop simulations with the VAFB LCC, KSC LCC, and OMC Sunnyvale.

6.4.2.23 A NASA Shuttle system simulator will be located at KSC for the training of NASA personnel. This simulator will be available for closed loop simulation with VAFB LCC, KSC LCC and OMC Houston.

6.4.2.24 The Tug operations shall be consistent with the safety implications of operating in the vicinity of the manned orbiter.

6.4.2.25 Orbiter control of all Tug critical functions shall be provided during deployment and retrieval operations.

6.4.2.26 Safety considerations require Orbiter control of Tug when it is within 20 nm of Orbiter.

6.4.2.27 No single failure shall result in unprogrammed motion of Tug.

6.4.2.28 Command override is available from either Orbiter or Mission Control.

6.4.2.29 Tug shall be capable of providing a low level of status monitoring to remote stations.

6.4.2.30 All polar orbit payloads will be launched from WTR.

6.4.3 Operations Complexity

The method used by GAC is to construct top level mission functional flow diagrams and assign weighted values to the various functions, thus giving a quantitative total value to each mission. Figure 6.4.3.1 lists the various tug missions and references the figure that shows computation of mission complexity for each tug configuration.

Complex operations will impact the tug design. Those operations designated as being complex in the functional flow for the single stage with AKS deployment mission, (fig. 6.4.3.2.-1), have been examined further. The functional flow is expanded to the second level in fig. 6.4.3.2-1 & 2 and impacted subsystems designated in the Functional Allocation Matrix fig. 6.4.3.2-3 & 4. System/subsystem requirements and studies necessary to proceed with the tug design have been identified in fig. 6.4.3.2-5 through 8.

TABLE 6.4.3-1 OPERATIONS COMPLEXITY

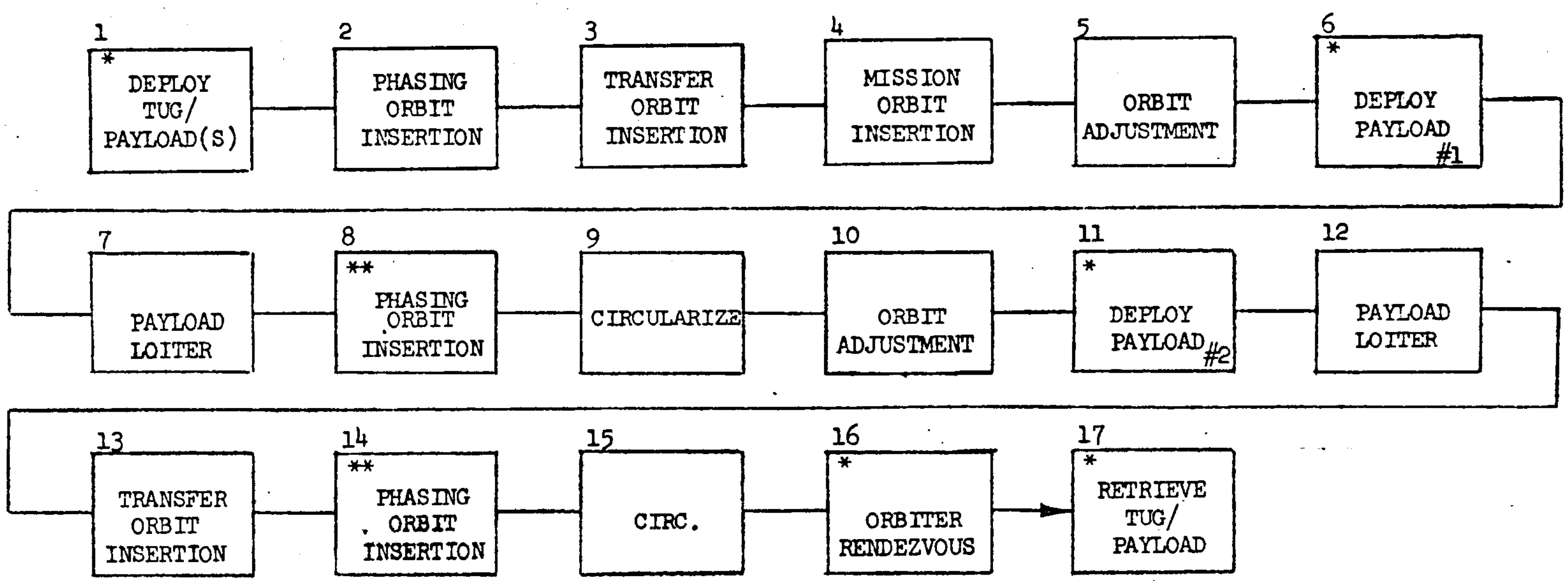
OPERATIONS COMPLEXITY-FIGURE NUMBERS

CONFIGURATION / MISSION	110A-1	410AD-2	310-3A	310RE-3A	320A-3A	320AE-3A	310-3B	310ARE-3B	510A-3B	510ADE-3B
SINGLE STAGE MULTIPLE DEPLOY	6.4.3.1	6.4.3.1	6.4.3.1	6.4.3.1			6.4.3.1	6.4.3.1	6.4.3.1	6.4.3.1
MULTIPLE DEPLOY WITH AKS FOR EACH PAYLOAD	6.4.3.2	6.4.3.2			6.4.3.2	6.4.3.2		6.4.3.2	6.4.3.2	6.4.3.2
SINGLE STAGE EXPENDED EXTREME FAR PLANET	6.4.3.3	6.4.3.3	6.4.3.3	6.4.3.3			6.4.3.3	6.4.3.3	6.4.3.3	6.4.3.3
SINGLE STAGE RETRIEVE DEORBITED PAYLOAD		6.4.3.4		6.4.3.4				6.4.3.4		6.4.3.4
SINGLE STAGE WITH AKS FAR PLANET	6.4.3.5	6.4.3.5			6.4.3.5	6.4.3.5		6.4.3.5		6.4.3.5
SINGLE STAGE WITH AKS/DKS ROUND TRIP		6.4.3.6						6.4.3.6		6.4.3.6
SINGLE STAGE DEPLOYMENT AND RETRIEVAL			6.4.3.7					6.4.3.7		6.4.3.7
SINGLE STAGE MULTIPLE DEPLOYMENT WITH RETRIEVAL DELAY				6.4.3.8				6.4.3.8		
TWO STAGE SLING SHOT DEPLOY					6.4.3.9	6.4.3.9				
TWO STAGE REVERSE SLING SHOT DEPLOY, DELAYED RETRIEVAL, ROUND TRIP						6.4.3.10				
DEPLOYMENT AND RETREVAL								6.4.3.11		
SINGLE STAGE SORTIE	6.4.3.12									
SINGLE STAGE MULTIPLE SERVICE			6.4.3.13							
SINGLE STAGE DELAYED RETRIEVAL				6.4.3.14						
SINGLE STAGE 2 DEPLOYMENTS AND RETRIEVAL				6.4.3.15						

FIG. 6.4.3.1

SINGLE STAGE MULTIPLE DEPLOY

CONFIGURATION: 110A-1 (Both Payloads are deployed in a single package)
410AD-2, 310-3A, 310RE-3A, 310-3B, 310ARE-3B, 510A-3B,
510ADE-3B



MAJOR FUNCTION MULTIPLIERS

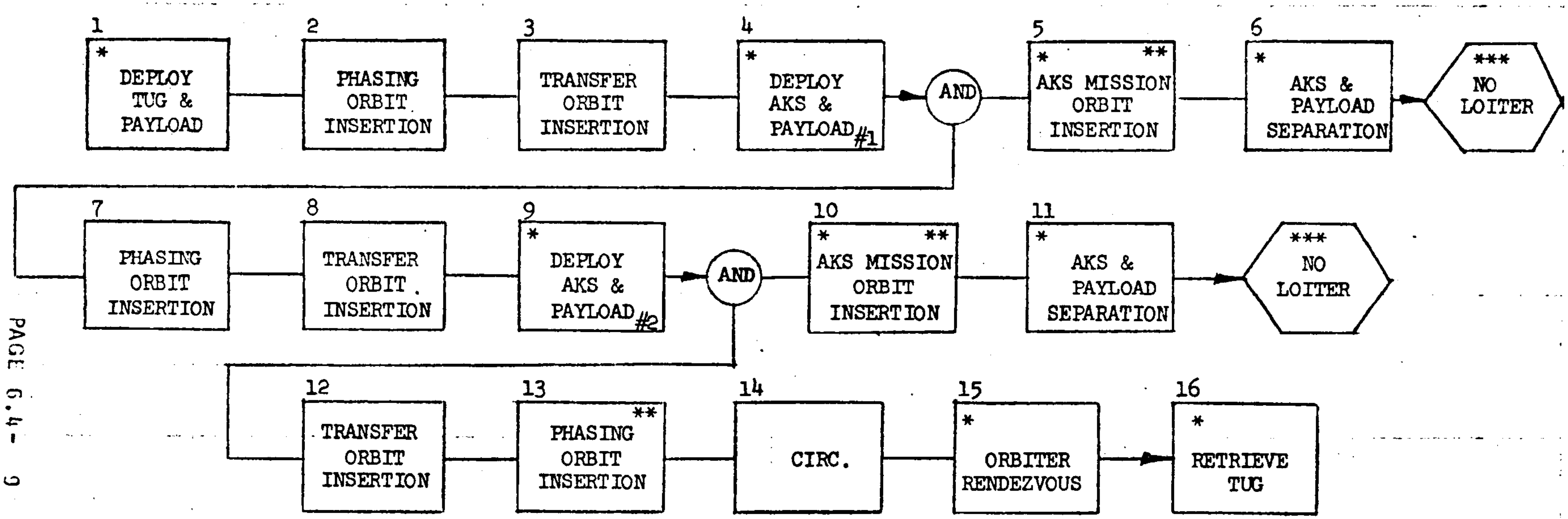
	1 P/L	2 P/L
o CREW SAFETY	2 X 8	2 X 8
o TUG RECOVERY	5 X 4	5 X 4
o PAYLOAD PLACEMENT	6 X 2	11 X 2
o PAYLOAD RETRIEVAL		

	1 P/L	2 P/L
* CRITICAL FUNCTIONS	4 X 8	5 X 8
** UNIQUE TRAJECTORY FACTORS	1 X 4	1 X 4
TOTAL	34	102

FIG. 6.4.3.1-1

FIG. 6.4.3.2 <u>SINGLE STAGE MULTIPLE DEPLOY WITH AKS FOR EACH PAYLOAD</u>

CONFIGURATION: 110A-1 (Both payloads are deployed in a single package)
410AD-2, 320A-3A, 320AE-3A, 310ARE-3B, 510A-3B (one payload only)
510ADE-3B



MAJOR FUNCTION MULTIPLIERS

	1 P/L	2 P/L
o CREW SAFETY	2 X 8	2 X 8
o TUG RECOVERY	5 X 4	5 X 4
o PAYLOAD PLACEMENT	6 X 2	11 X 2
o PAYLOAD RETRIEVAL		

	1 P/L	2 P/L
* CRITICAL FUNCTIONS	6 X 8	9 X 8
** UNIQUE TRAJ. FACTORS	2 X 4	3 X 4
*** DEFICIENT FUNCTIONS	1 X 4	2 X 4
TOTAL	108	150

FIG. 6.4.3.2-1

FIG. 6.4.3.2.1 MISSION FUNCTIONAL FLOW LEVEL II SIGNIFICANT EVENTS

SINGLE STAGE WITH AKS - DEPLOYMENT

CONFIGURATION: 110A

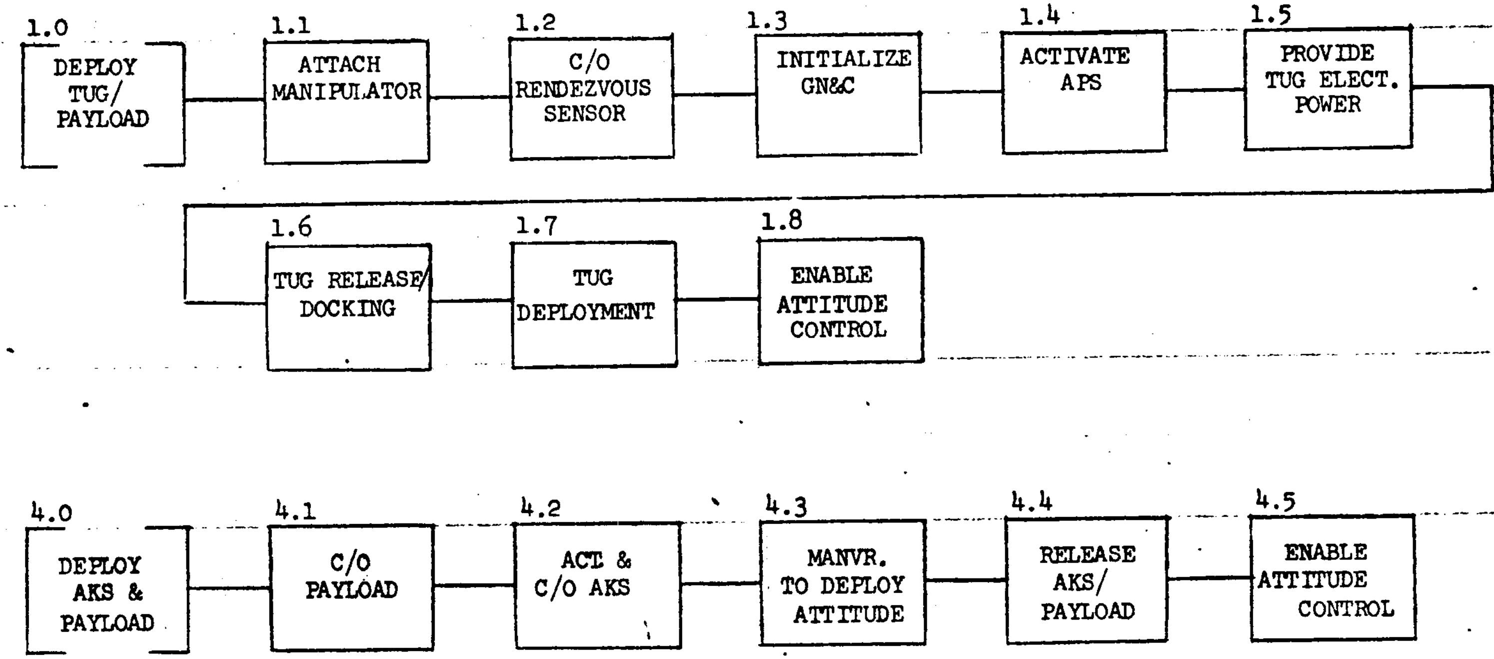


FIGURE 6.4.3.2-1

FIG. 6.4.3.2.2

MISSION FUNCTIONAL FLOW LEVEL II SIGNIFICANT EVENTS

SINGLE STAGE WITH AKS DEPLOYMENT

CONFIGURATION: 110A

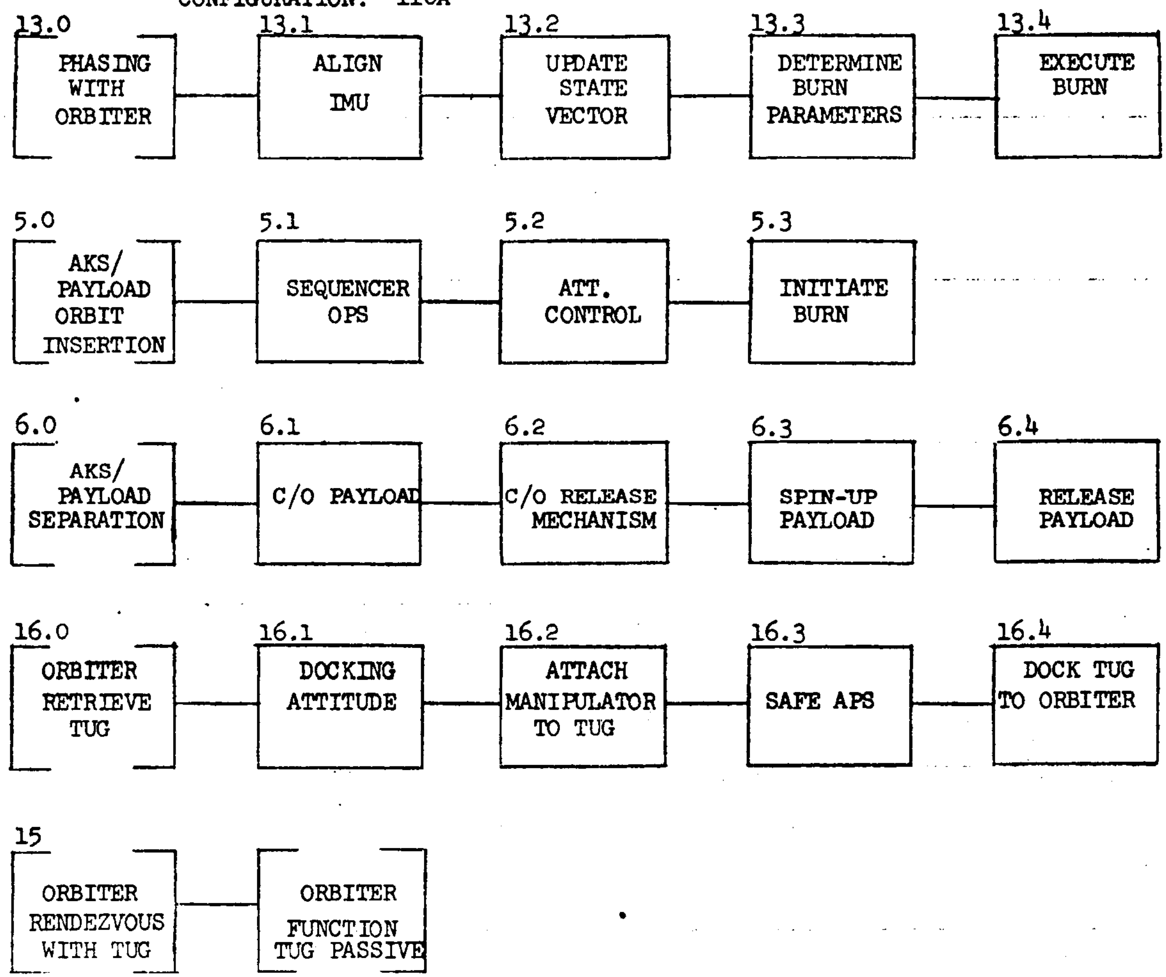


FIGURE 6.4.3.2-2

FIG 6.4.

FUNCTION ALLOCATION MATRIX

MISSION FUNCTION \ SYS./SUBSYSTEM	SAFETY	PAYLOAD INTERFACE	ORBITER INTERFACE	STRUCT.	THERM.	DMS	GN&C	COMM.	EPS	MPS	APS	INST.	POWER DIST.
1.0 DEPLOY TUG													
1.1 ATTACH MANIPULATOR			O	O									
1.2 ℅ RENDEZVOUS SENSOR						O	O						
1.3 INITIALIZE GN&C			O			O	O						
1.4 ACTIVATE APS						O					O		
1.5 PROVIDE TUG ELECT. POWER	O		O			O			O				
1.6 ℅ TUG RELEASE/DOCKING			O	O		O							
1.7 TUG DEPLOYMENT	O		O	O									
1.8 ENABLE ATTITUDE CONTROL	O		O			O		O					
4.0 DEPLOY AKS & PAYLOAD													
4.1 ℅ PAYLOAD		O				O							
4.2 ACTIVATE/CHECKOUT AKS							O	O	O	O	O	O	O
4.3 MANEUVER TO DEPLOY ATT.						O	O						
4.4 RELEASE AKS & PAYLOAD				O		O							
4.5 ENABLE ATTITUDE CONTROL						O							
5.0 AKS/PAYLOAD ORBIT INSERT.													
5.1 SEQUENCER OPERATION							O						
5.2 ATTITUDE CONTROL							O				O		
5.3 INITIATE BURN							O			O			

FIG. 6.4.3.2-3

FIG. 6.4.3.2-4

FUNCTION ALLOCATION MATRIX

MISSION FUNCTION \ SYS./SUBSYSTEM	SAFETY	PAYLOAD INTERFACE	ORBITER INTERFACE	STRUCT.	THERM.	DMS	G/N&C	COMM.	EPS	MPS	APS	INST.	POWER DIST.
6.0 AKS/PAYLOAD SEPARATION													
6.1 C/O PAYLOAD						O							
6.2 C/O RELEASE MECHANISM				O		O							
6.3 SPIN-UP PAYLOAD		O				O	O						
6.4 RELEASE PAYLOAD		O		O		O							
13.0 PHASING WITH ORBITER													
13.1 ALIGN IMU						O	O						
13.2 UPDATE STATE VECTOR			O										
13.3 DETERMINE BURN PARAMETERS						O							
13.4 EXECUTE BURN						O				O			
16.0 ORBITER RETRIEVE TUG													
16.1 DOCKING ATTITUDE							O						
16.2 ATTACH MANIPULATOR	O			O									
16.3 SAFE APS	O					O					O		
16.4 DOCK TUG TO ORBITER	O			O									

TUG REQUIREMENTS IDENTIFICATION-CONFIGURATION 110A

MISSION FUNCTION	REQUIREMENT	ISSUE	STUDIES REQUIRED
1.0 Deploy Tug/ Payload			
1.1 Attach Manipulators	Orbiter Manipulators will be used to deploy Tug	o Mount compatible grab stanchions on Tug within reach of manipulators	None(manipulators reach 139"-515" & stanchion configuration specified)
		o Structurally attach stanchions to take manipulator imposed load	Determine attachment loads to design support structure
1.2 c/o Rendezvous Sensor	Provide sensor activation and c/o criteria	o Determine Criteria	Select hardware and analyze operational characteristics.
		o DMS must provide activation and process status data	Determine activation discrete and implement criteria for acceptable operation.
1.3 Initialize GN&C	Provide alignment and navigation data to Tug	o Orbiter to provide initialization data to Tug	Determine format and accuracy of Tug required data
		o DMS Process Orbiter data and command IMU alignment	Determine data storage and transfer requirements
		o GN&C accept commands and align inertial platform	Evaluate methods of aligning platform
1.4 Activate APS	Assure APS ready for usage	o DMS command to pressurize and c/o APS	Determine data storage and command requirements.
		o APS c/o while Tug attached to orbiter	Evaluate operation of thrusters while attached to Orbiter

FIG. 6.4.3.2-5

FIG. 6.4.3-2-6

TUG REQUIREMENTS IDENTIFICATION-CONFIGURATION 110A

MISSION FUNCTION	REQUIREMENT	ISSUE	STUDIES REQUIRED
1.5 Provide Tug Electrical Power	Switch from Orbiter to Tug Electrical Power	o Design of Tug primary & backup power supply	Determine backup power supply requirements
		o Orbiter power allocated for Tug c/o	Determine Tug power for c/p
		o DMS to control power switch over	Select best time for power switch over
		o EPS to provide power source and switchover design	Design primary & backup power source also switch over mechanism
1.6 c/o Tug release/docking mechanism	Verify that Tug Orbiter interface for release/docking is operational	o Orbiter display/controls to show Tug ready for deployment	Type of information to be displayed to crew
		o Criteria for payload bay adapter readiness	Determine sensors/signals required to establish adapter status
		o DMS signal interface to determine Tug ready	Determine Go/NoGo criteria for Tug deployment
1.7 Tug Deployment	The Tug will be removed from the Orbiter payload bay by crew control	o Crew/Orbiter safety during deployment	Evaluate Tug systems for safe operation
		o Orbiter manipulator control of Tug	Develop control procedures
		o Tug/Adapter structural interface	Determine Tug/Adapter rigidity requirements to assure adequate clearance.

TUG REQUIREMENTS IDENTIFICATION-CONFIGURATION 110A

MISSION FUNCTION	REQUIREMENT	ISSUE	STUDIES REQUIRED
1.8 Enable Attitude Control	Transmit signal to Tug enabling attitude control & commencement of Tug mission	o Tug/Orbiter separation prior to removal of Tug inhibit	Determine safe distance between Tug & Orbiter prior to enabling Tug
		o Implementation of Tug activation signal	Determine signal code and method of crew enabling Tug.
		o DMS output upon receiving proceed signal	Determine functions to be implemented.
		o Comm. signal complexity to assure no receipt of false signals	Establish signal characteristics
4.0 Deploy AKS & Payload			
4.1 c/o Payload	Assure functional integrity of payload	o Tug determination of payload status prior activation	Review payloads to determine extent of c/o required prior activation
		o DMS control of payload and data handling	Determine commands & data criteria for satisfactory payload c/o
4.2 Activate & c/o AKS	Assure operational readiness of AKS prior deployment	o Activation of Guidance, Comm, EPS, MPS, APS, Inst. Power Dist.	Determine sequence of activation & Go/NoGo criteria for AKS subsystems

FIG. 6.4.3.2-7

TUG REQUIREMENTS IDENTIFICATION-CONFIGURATION 110A

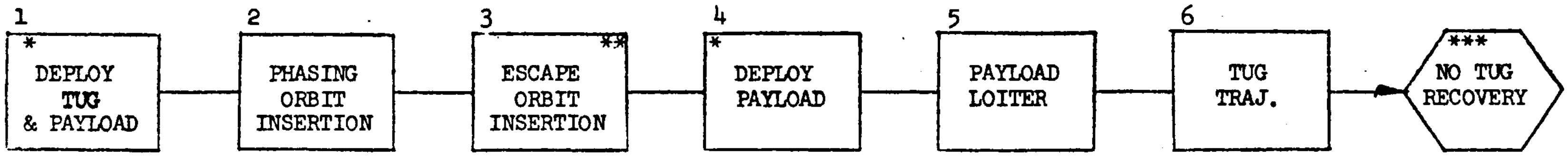
MISSION FUNCTION	REQUIREMENT	ISSUE	STUDIES REQUIRED
4.3 Maneuver to Deployment Attitude	Tug shall establish AKS burn attitude	Accuracy of Tug attitude for subsequent AKS burn	Determine AKS burn attitude requirements
4.4 Release AKS & Payload	AKS clean separation from Tug	Method of separating AKS/Tug	Determine method of separating AKS/Tug with minimum AKS disturbance.
4.5 Enable Attitude Control	At AKS/Tug separation the AKS attitude control shall be functioning	Method of activating AKS attitude control	Determine implementation of attitude control and commencement of AKS mission activities
5.0 AKS/Payload Orbit Insertion			
5.1 Sequencer Operation	AKS mission events shall be controlled by an onboard sequencer	Adequacy of autonomy Level 1 sequencer control	Determine if ground control required during AKS operation
5.2 Attitude Control	AKS shall hold attitude to meet burn requirements	Capability of AKS to hold attitude	Determine attitude control design to meet burn requirements
5.3 Initiate Burn	Initiate burn at required time to place payload in mission orbit	Accuracy of sequencer	Obtain simple, reliable sequencer

FIG. 6.4.3.2-8

FIG. 6.4.3.3

<u>SINGLE STAGE EXPENDED EXTREME FAR PLANET</u>

CONFIGURATION: 110A-1, 410AD-2, 310-3A, 310RE-3A, 310-3B, 310ARE-3B
510ADE-3B



MAJOR FUNCTIONAL MULTIPLIERS

- o CREW SAFETY 1 X 8
- o TUG RECOVERY
- o PAYLOAD PLACEMENT 4 X 2
- o PAYLOAD RETRIEVAL

* CRITICAL FUNCTIONS 2 X 8

** UNIQUE TRAJECTORY FACTORS 1 X 4

*** DEFICIENT FUNCTION 1 X 4

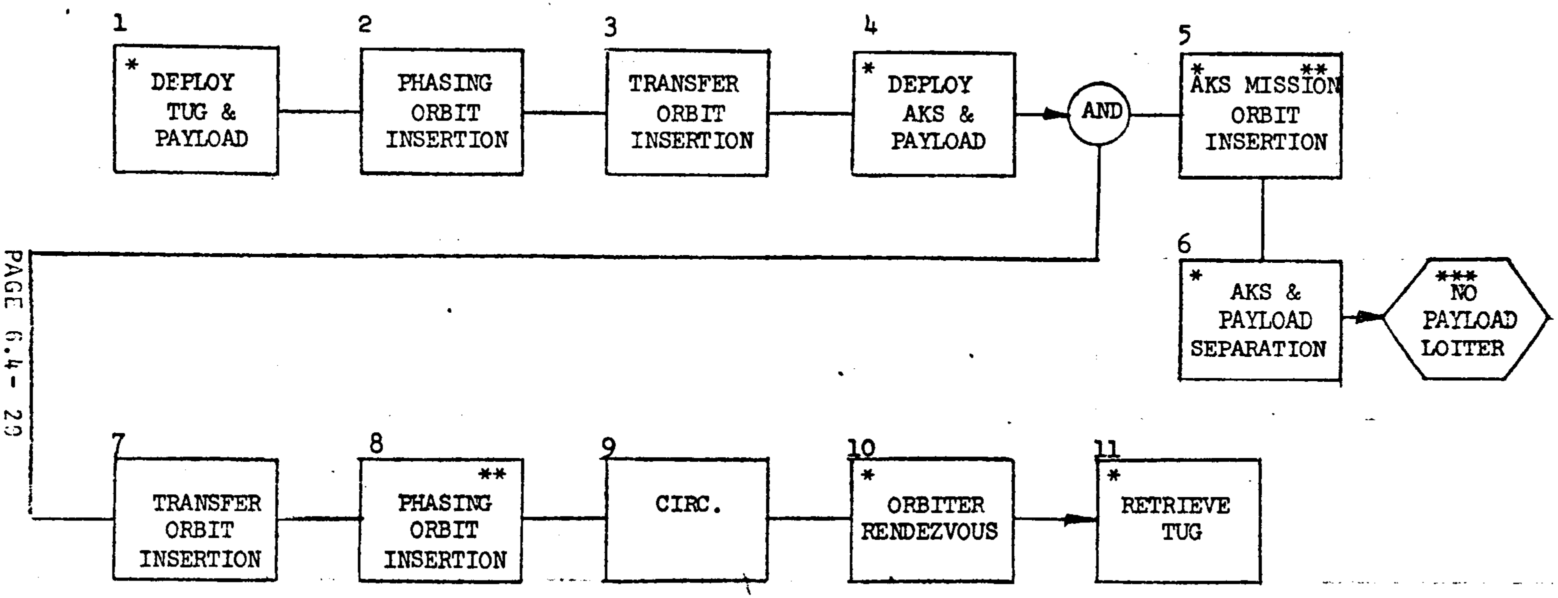
TOTAL 40

FIG. 6.4.3.3-1

FIG. 6.4.3.5

SINGLE STAGE WITH AKS FAR PLANET

CONFIGURATION: 410AD-2, 320A-3A, 320AE-3A, 310ARE-3B
510ADE-3B



MAJOR FUNCTION MULTIPLIERS

o	CREW SAFETY	2 X 8
o	TUG RECOVERY	5 X 4
o	PAYLOAD PLACEMENT	6 X 2
o	PAYLOAD RETRIEVAL	

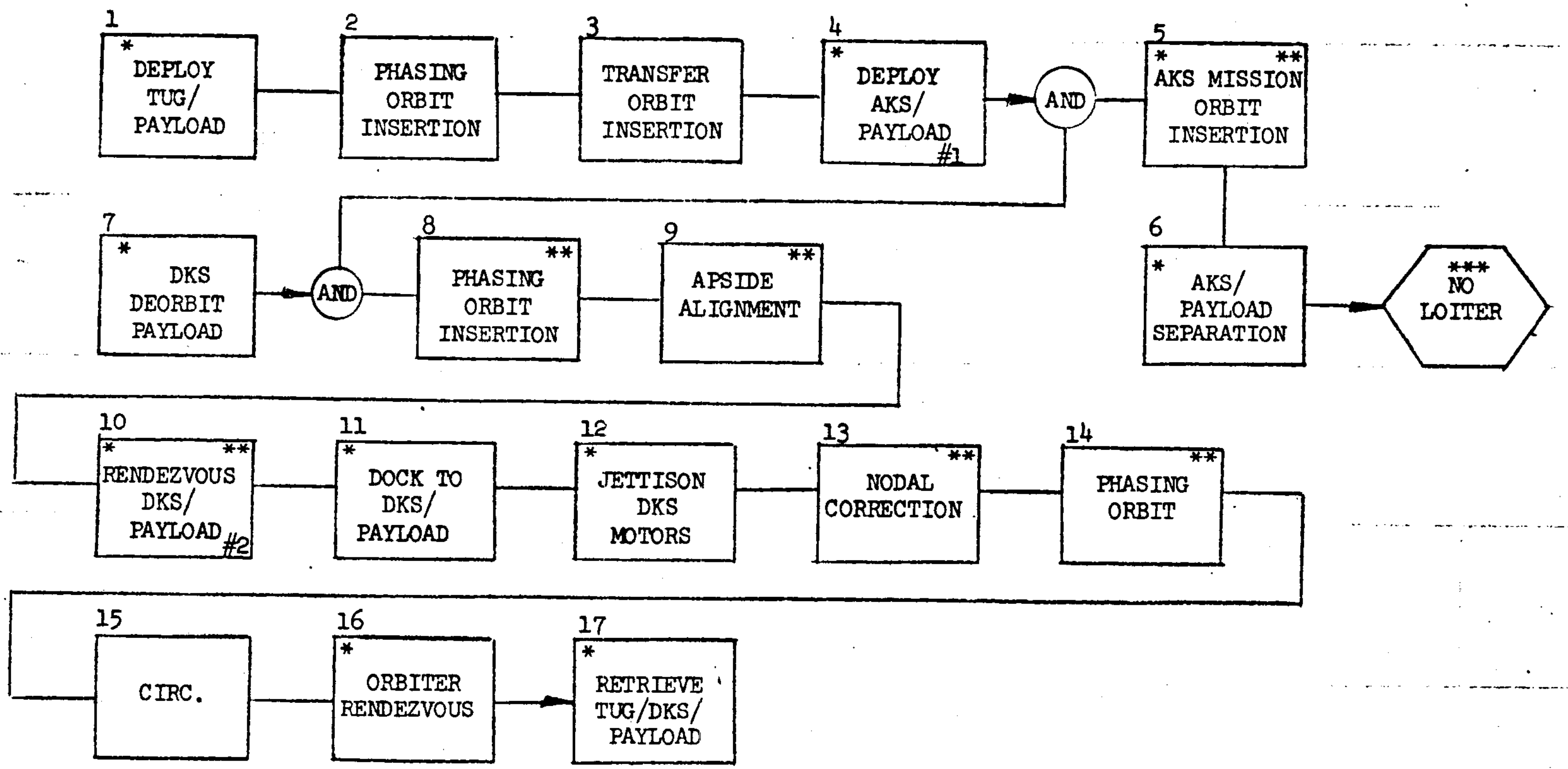
*	CRITICAL FUNCTIONS	6 X 8
**	UNIQUE TRAJ. FACTORS	2 X 4
***	DEFICIENT FUNCTIONS	1 X 4
	TOTAL	108

FIG. 6.4.3.5-1

FIG. 6.4.3.6

SINGLE STAGE WITH AKS/DKS ROUND TRIP

CONFIGURATION: 410AD-2, 510ADE-3B



MAJOR FUNCTION MULTIPLIERS

- o CREW SAFTY 2 X 8
- o TUG RECOVERY 6 X 4
- o PAYLOAD PLACEMENT 6 X 2
- o PAYLOAD RETRIEVAL 11 X 1

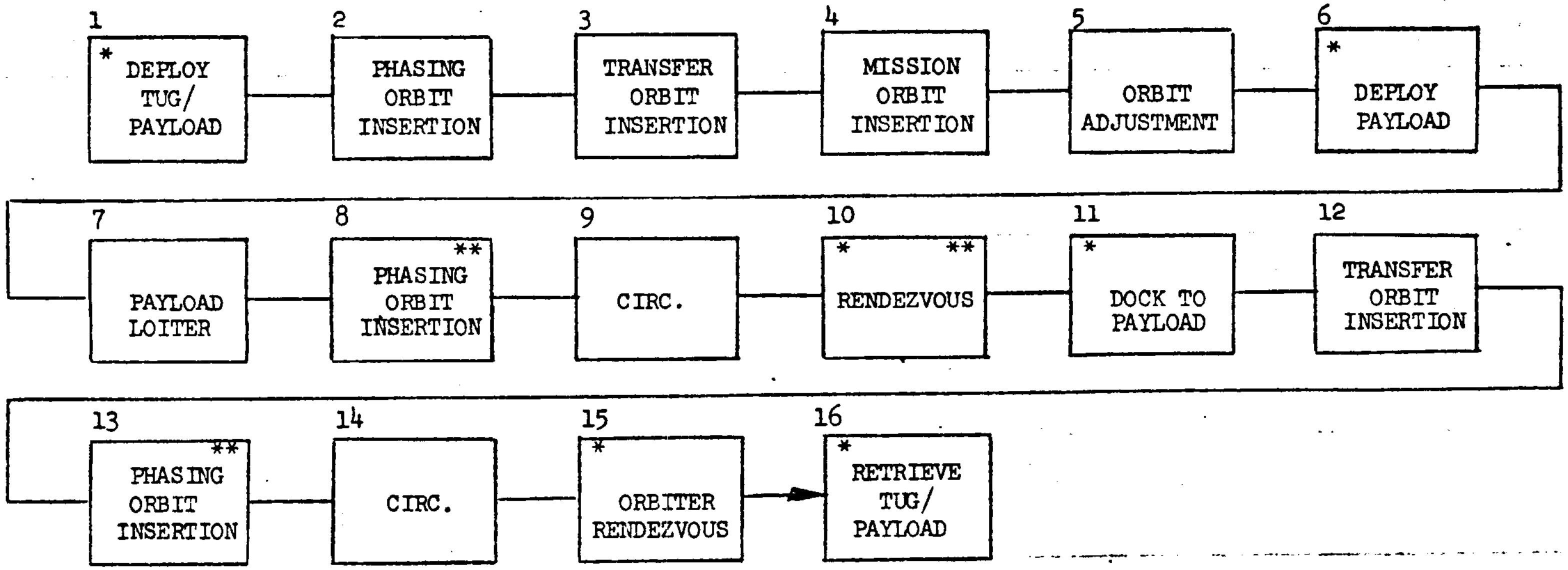
*	CRITICAL FUNCTIONS	9 X 8
**	UNIQUE TRAJECTORY FACTORS	6 X 4
***	DEFICIENT FUNCTION	1 X 4
	TOTAL	163

FIG. 6.4.3.6-1

FIG. 6.4.3.7

SINGLE STAGE DEPLOYMENT AND RETRIEVAL

CONFIGURATION: 410AD-2, 310RE-3A, 310ARE-3B, 510ADE-3B



MAJOR FUNCTION MULTIPLIERS

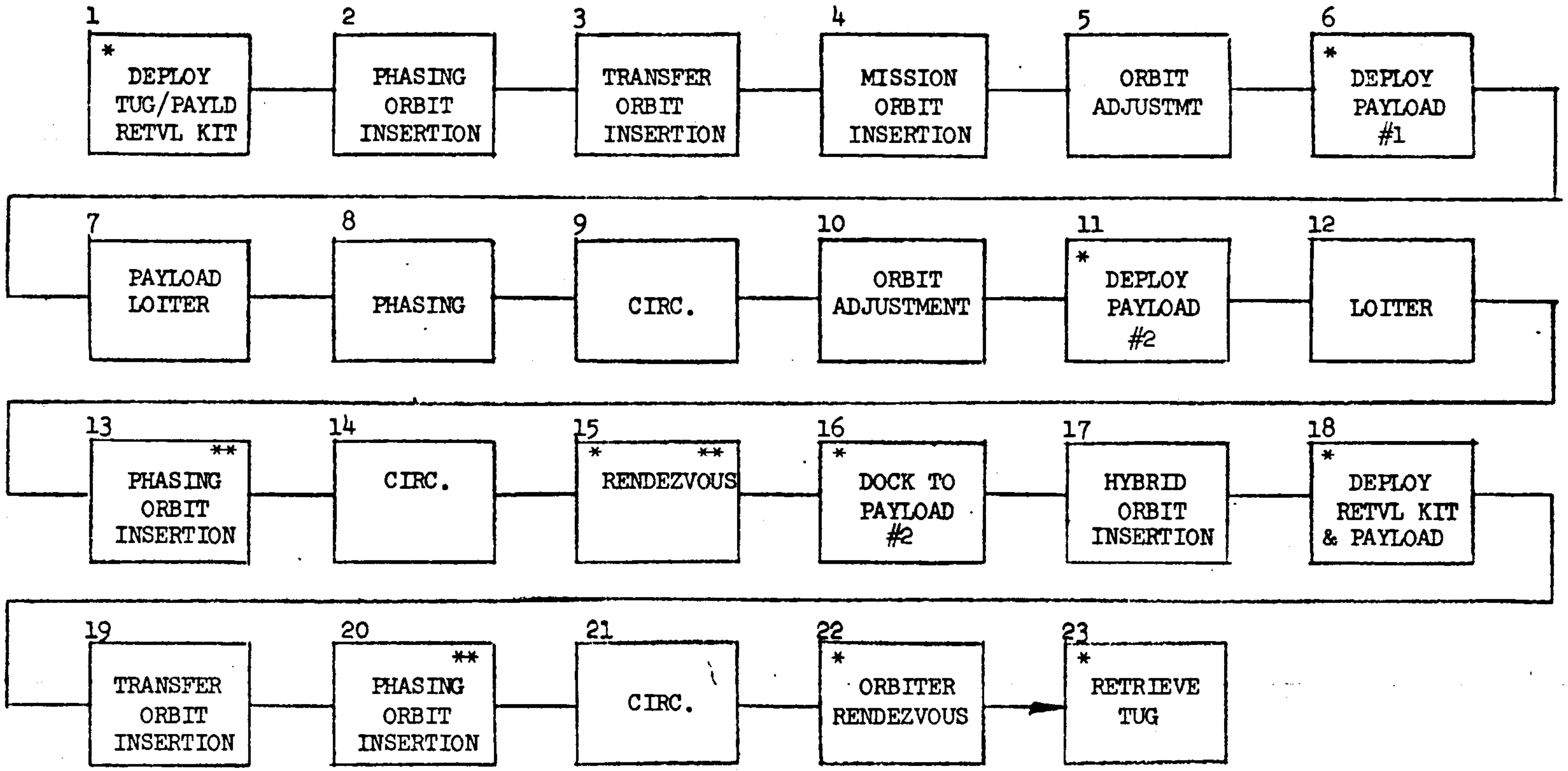
o CREW SAFETY	2 X 8
o TUG RECOVERY	5 X 4
o PAYLOAD PLACEMENT	6 X 2
o PAYLOAD RETRIEVAL	9 X 1

* CRITICAL FUNCTIONS	6 X 8
** UNIQUE TRAJECTORY FACTORS	3 X 4
TOTAL	117

FIG. 6.4.3.7-1

FIG. 6.4.3.8 SINGLE STAGE MULTIPLE DEPOYMENT, WITH RETRIEVAL DELAY

CONFIGURATION: 310RE-3A, 320AE-3A (2 Payloads only), 310ARE-3B (1 Payload only)



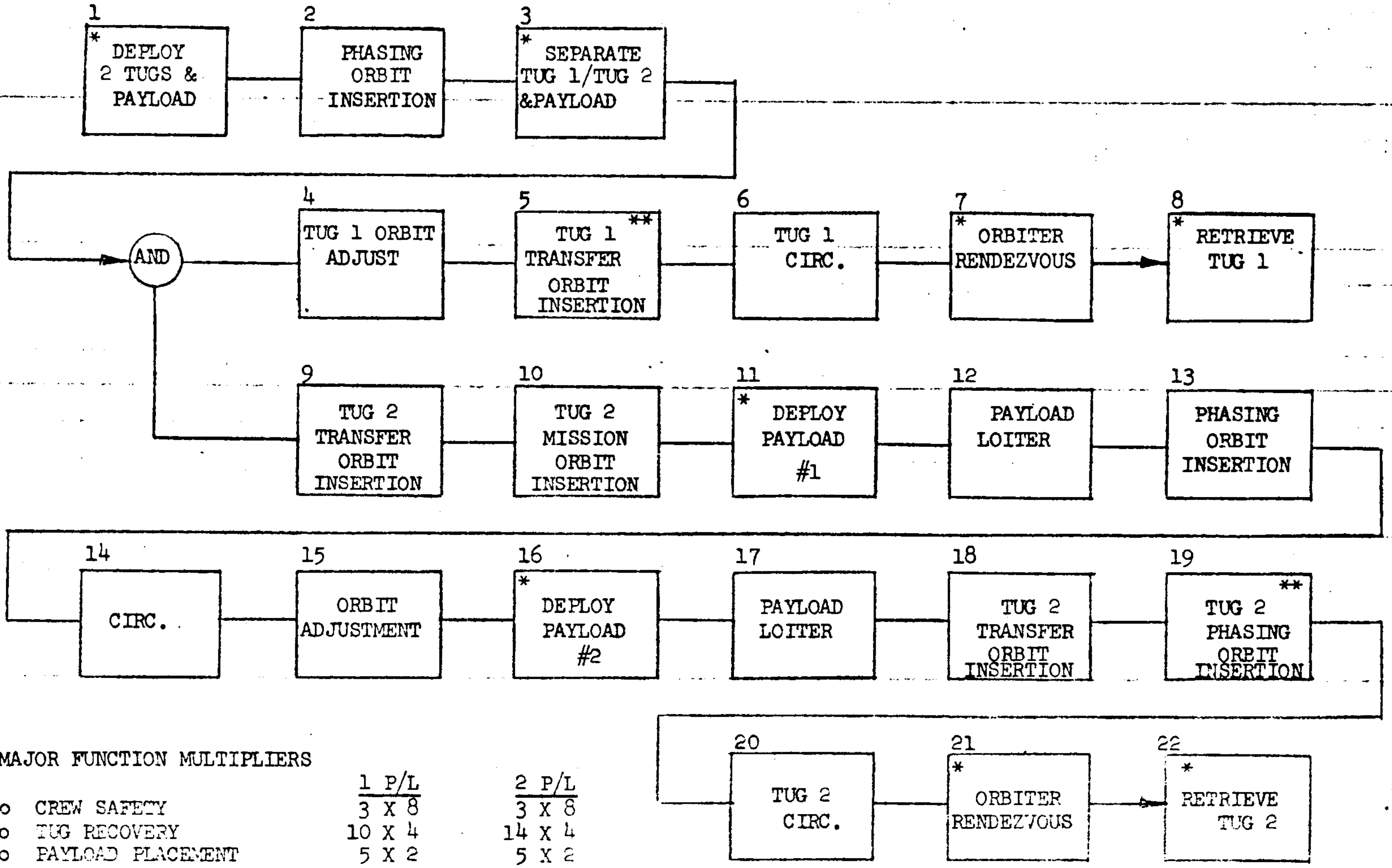
MAJOR FUNCTION MULTIPLIERS	1 P/L	2 P/L
o CREW SAFETY	2 X 8	2 X 8
o TUG RECOVERY	7 X 4	7 X 4
o PAYLOAD PLACEMENT	6 X 2	11 X 2
o PAYLOAD RETRIEVAL	6 X 1	6 X 1

	1 P/L	2 P/L
* CRITICAL FUNCTIONS	7 X 8	8 X 8
** UNIQUE TRAJECTORY FACTORS	3 X 4	3 X 4
TOTAL	130	148

FIG. 6.4.3.8-1

FIG. 6.4.3.9 **TWO STAGE SLING SHOT DEPLOY TWO PAYLOADS**

CONFIGURATION: 320A-3A (one payload only), 320AE-3A



MAJOR FUNCTION MULTIPLIERS

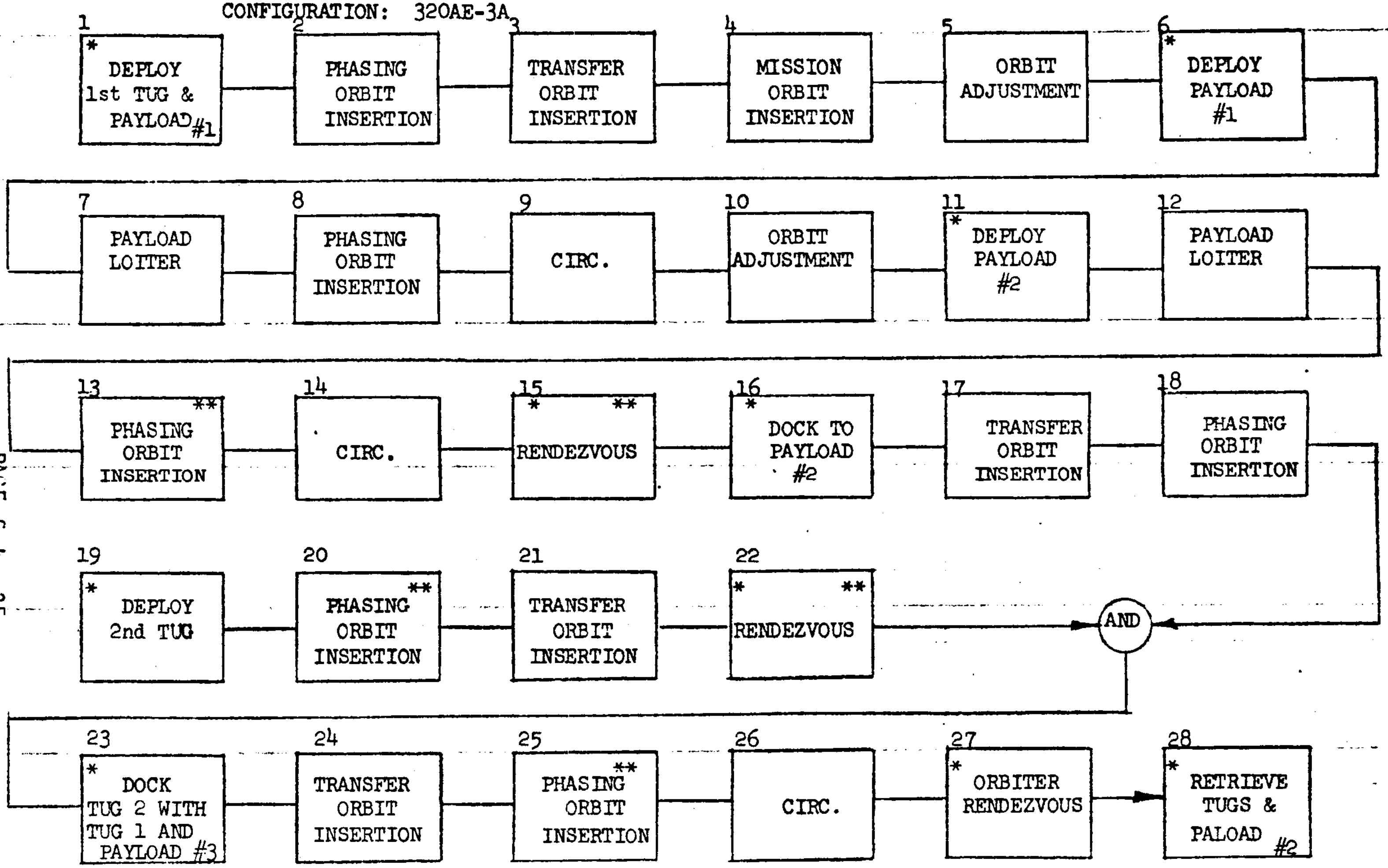
	1 P/L	2 P/L
o CREW SAFETY	3 X 8	3 X 8
o TUG RECOVERY	10 X 4	14 X 4
o PAYLOAD PLACEMENT	5 X 2	5 X 2
o PAYLOAD RETRIEVAL		

	1 P/L	2 P/L
* CRITICAL FUNCTIONS	7 X 8	8 X 8
** UNIQUE TRAJECTORY FACTORS	2 X 4	2 X 4
TOTAL	[illegible]	162

FIG 6.4.3.9-1

FIG. 6.4.3.10 TWO STAGE REVERSE SLING SHOT DEPLOY DELAYED RETRIEVAL ROUND TRIP

CONFIGURATION: 320AE-3A



MAJOR FUNCTION MULTIPLIERS	1 P/L	2 P/L
o CREW SAFETY	3 X 8	3 X 8
o TUG RECOVERY	8 X 4	8 X 4
o PAYLOAD PLACEMENT	6 X 2	10 X 2
o PAYLOAD RETRIEVAL	16 X 1	16 X 1

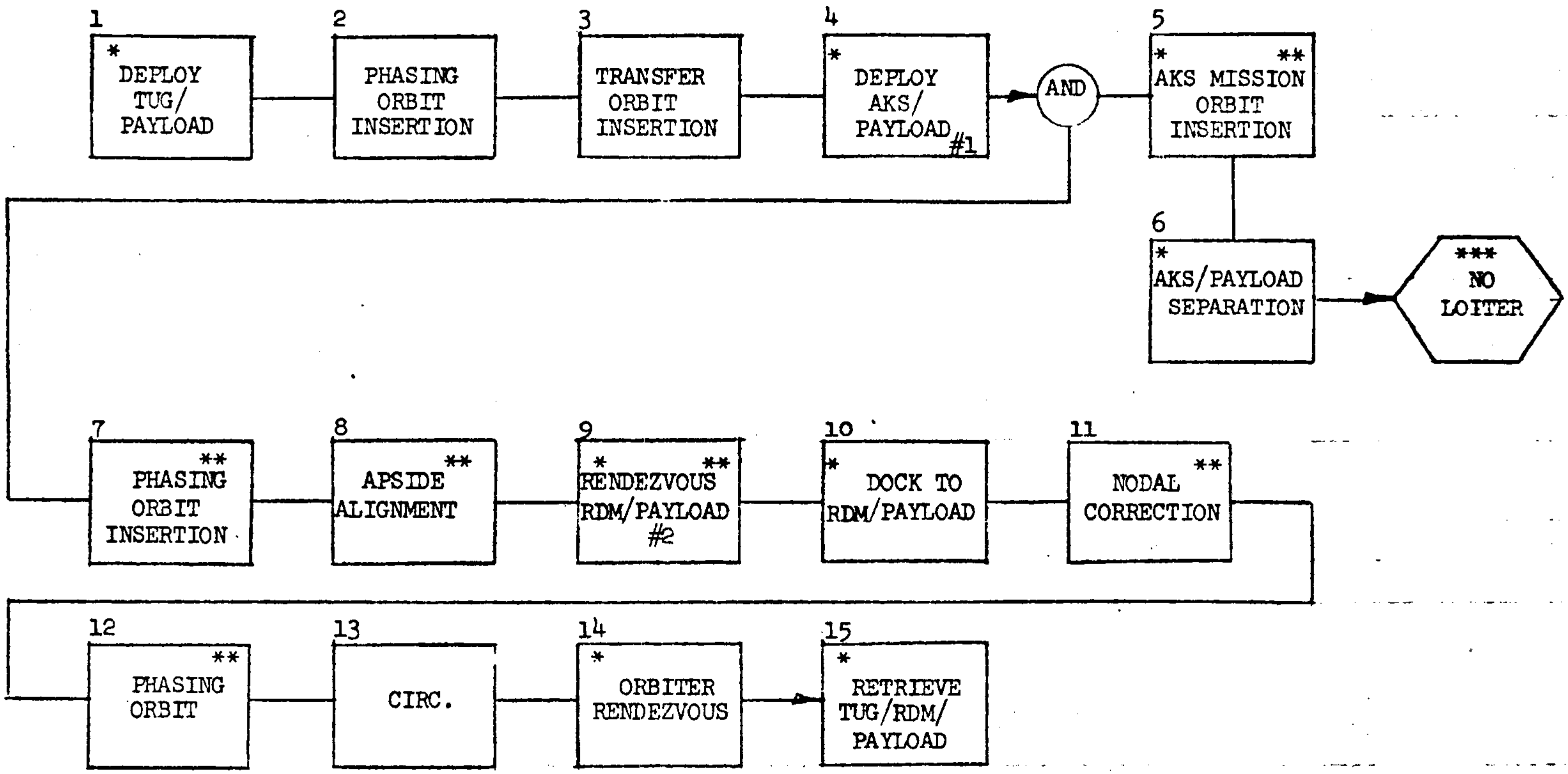
	1 P/L	2 P/L
* CRITICAL FUNCTIONS	9 X 8	10 X 8
** UNIQUE TRAJECTORY FACTORS	5 X 4	5 X 4
TOTAL	176	192

FIG. 6.4.3.10-1

FIG. 6.4.3.11

SINGLE STAGE DEPLOYMENT WITH AKS AND DELAYED RETRIEVAL

CONFIGURATION: 310ARE-3B



MAJOR FUNCTION MULTIPLIERS

o CREW SAFETY	2 X 8
o TUG RECOVERY	5 X 4
o PAYLOAD PLACEMENT	6 X 2
o PAYLOAD RETRIEVAL	9 X 1

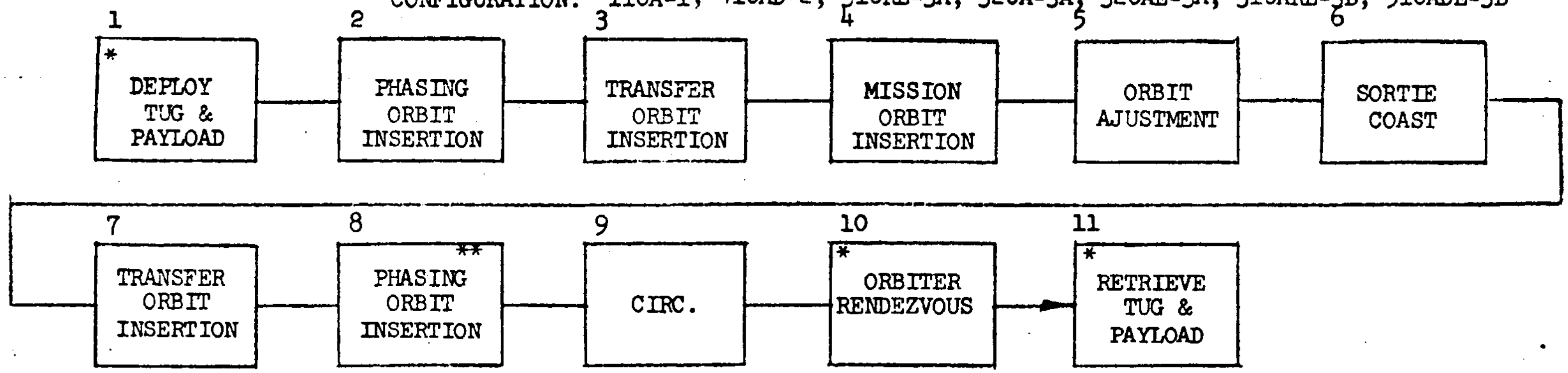
* CRITICAL FUNCTIONS	8 X 8
** UNIQUE TRAJECTORY FACTORS	6 X 4
*** DEFICIENT FUNCTION	1 X 4
TOTAL	142

FIG. 6.4.3.11-1

FIG. 6.4.3.12

SINGLE STAGE SORTIE

CONFIGURATION: 110A-1, 410AD-2, 310RE-3A, 320A-3A, 320AE-3A, 310ARE-3B, 510ADE-3B



MAJOR FUNCTION MULTIPLIERS

o CREW SAFETY	2 X 8
o TUG RECOVERY	5 X 4
o PAYLOAD PLACEMENT	5 X 2
o PAYLOAD RETRIEVAL	5 X 1

*	CRITICAL FUNCTIONS	1 X 8
**	UNIQUE TRAJECTORY FACTORS	3 X 4

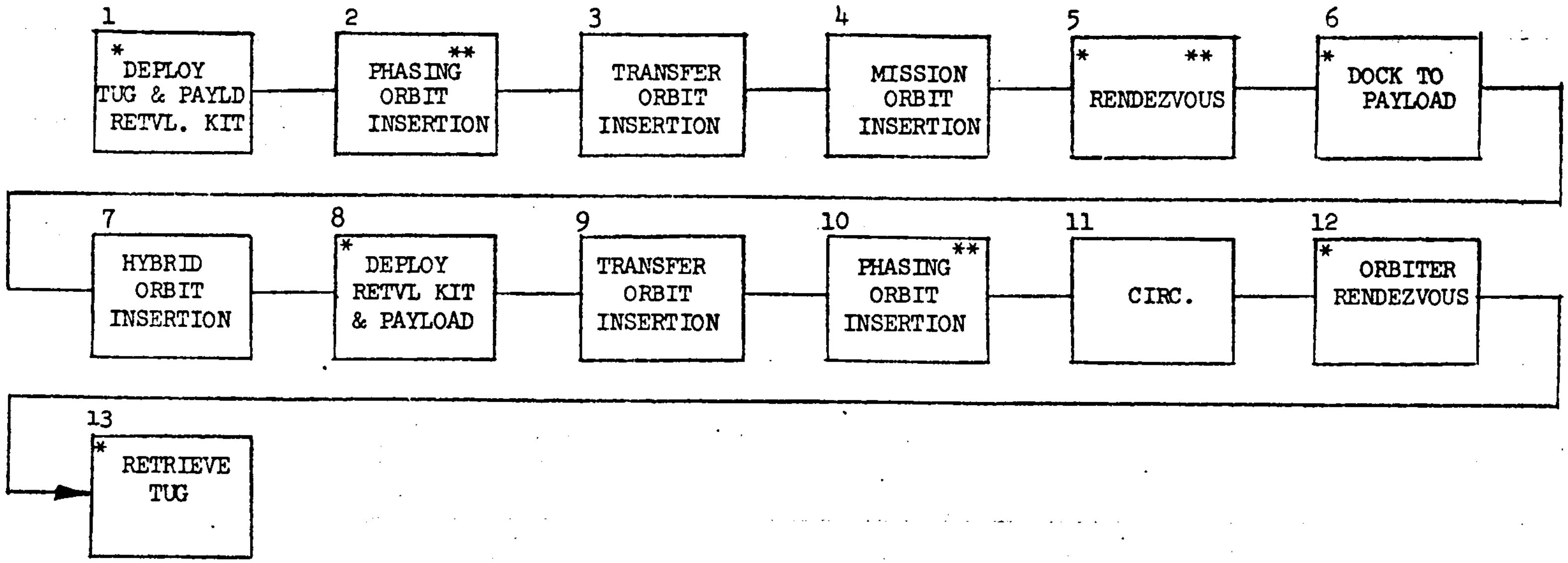
TOTAL 71

FIG. 6.4.3.12-1

FIG. 6.4.3.14

SINGLE STAGE RETRIEVAL DELAYED

CONFIGURATION: 31ORE-3A



MAJOR FUNCTION MULTIPLIERS

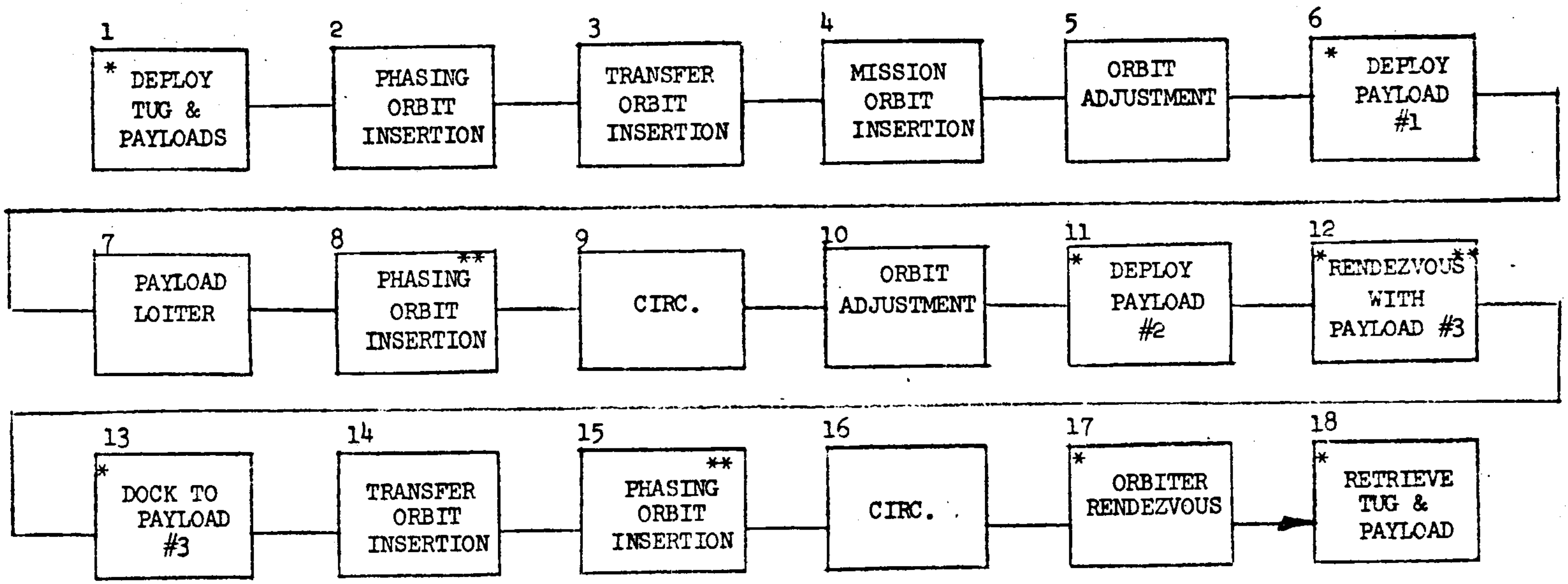
o CREW SAFETY	2 X 8
o TUG RECOVERY	5 X 4
o PAYLOAD PLACEMENT	8 X 2
o PAYLOAD RETRIEVAL	

* CRITICAL FUNCTIONS	3 X 8
** UNIQUE TRAJECTORY FACTORS	3 X 4
TOTAL	88

FIG. 6.4.3.14-1

FIG. 6.4.3.15 SINGLE STAGE MULTIPLE DEPLOYMENTS AND RETRIEVAL

CONFIGURATION: 31ORE-3A



MAJOR FUNCTION MULTIPLIERS

o CREW SAFETY	2 X 8
o TUG RECOVERY	5 X 4
o PAYLOAD PLACEMENT	11 X 2
o PAYLOAD RETRIEVAL	13 X 1

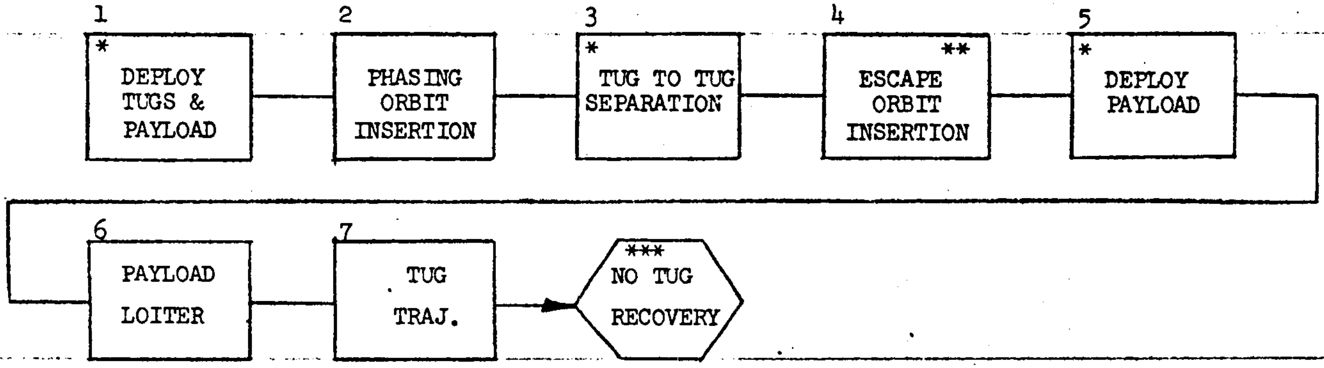
* CRITICAL FUNCTIONS	7 X 8
** UNIQUE TRAJECTORY FACTORS	3 X 4
TOTAL	139

FIG. 6.4.3.15-1

FIG. 6.4.3.16

TWO STAGE EXPENDED EXTREME FAR PLANET

CONFIGURATION: 320AE-3A



MAJOR FUNCTIONAL MULTIPLIERS

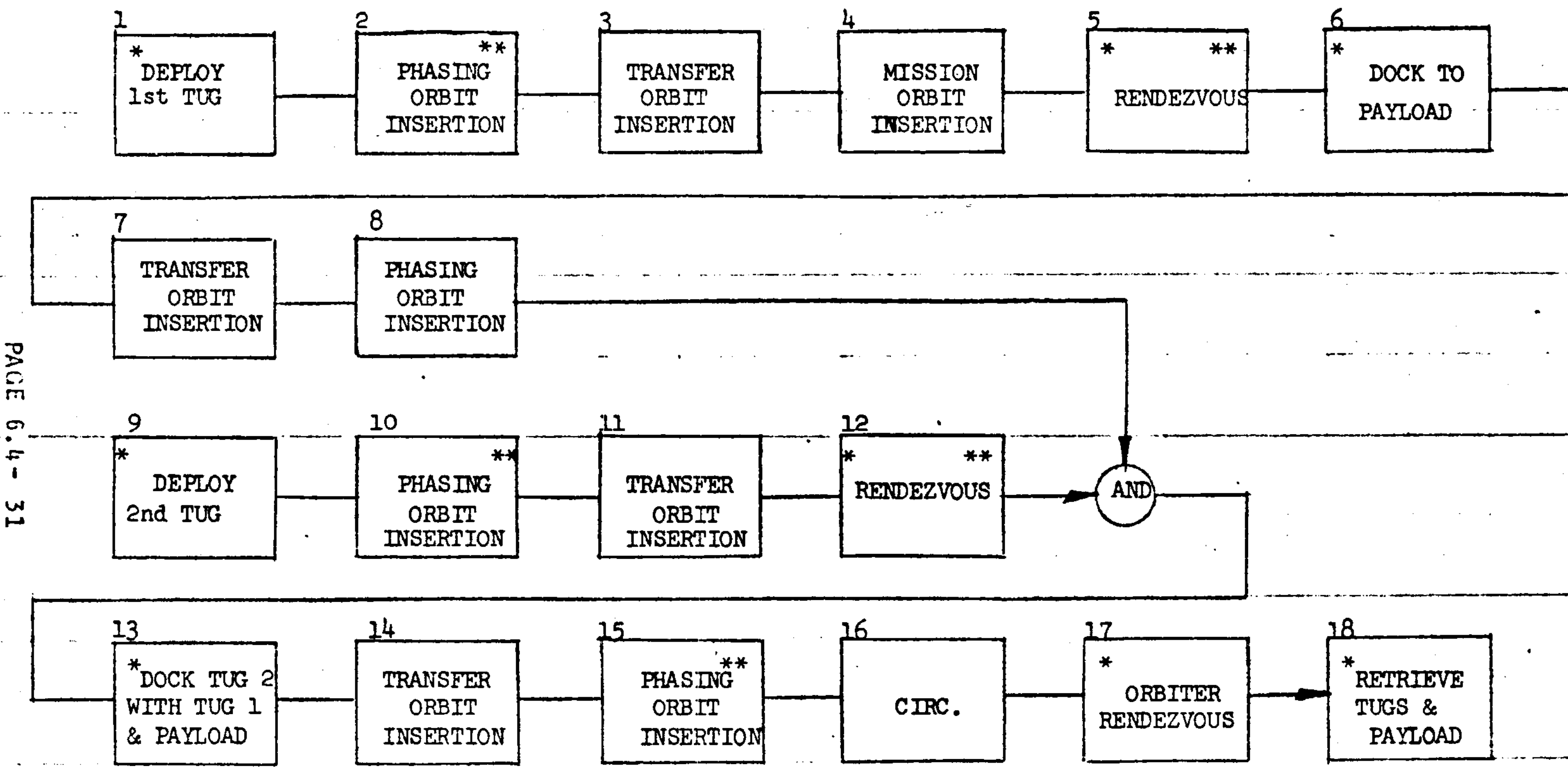
o CREW SAFETY	1 X 8	*	CRITICAL FUNCTIONS	3 X 8
o TUG RECOVERY	—	**	UNIQUE TRAJECTORY FACTORS	1 X 4
o PAYLOAD PLACEMENT	5 X 2	***	DEFICIENT FUNCTION	1 X 4
o PAYLOAD RETRIEVAL				

TOTAL 50

FIG. 6.4.3.16-1

FIG. 6.4.3.17 TWO STAGE RETRIEVE (REVERSE SLING SHOT)

CONFIGURATION: 320AE-3A



MAJOR FUNCTION MULTIPLIERS

o CREW SAFETY	3 X 8
o TUG RECOVERY	8 X 4
o PAYLOAD PLACEMENT	-
o PAYLOAD RETRIEVAL	12 X 1

*	CRITICAL FUNCTIONS	8 X 8
**	UNIQUE TRAJECTORY FACTORS	5 X 4
	TOTAL	152

FIG. 6.4.3.17-1

6.4.4 Baseline Cost Data

- Assumptions

  a) Government manpower requirements are 50% of contractors during DDT&E.

  b) Mission operations will be completely staffed by the government in 1982 after two years of flights.

  c) NASA will be the Tug Contracting Agency, therefore, will conduct the test flight in December '79.

  d) Flight schedule:

	1979	1980	1981	1982
NASA	1	2	6	Mission Model
DOD	-	1	6	Mission Model

  e) NASA will develop operational computer programs, generate operational data and provide it to DOD.

  f) NASA & DOD, MCC will be utilized around the clock.

- Methodology

  - The approach used to define the operations cost data:

    a) Establish the tasks to be done in each WBS.

    b) Schedule the tasks against program milestones.

    c) Assign contractor manpower to each task.

    d) Review other programs for comparison (Apollo, OAO, Titan).

    e) Sum manpower by catagories and convert to dollar value.

- Methodology: (Continued)

  - The method used to determine manpower requirements was to schedule contractor manpower for a round trip deployment and retrieval mission, then assume government manpower at 50% of the contractor. Since it was assumed that NASA would be the contracting agency, they would supply data to DOD. If the decision is made that DOD will contract the Tug Program, then the manpower allocation would be reversed between DOD/Contractor and NASA/Contractor.

    Both NASA & DOD must be involved in establishing the initial Tug requirements, therefore, manpower has been scheduled for both agencies to participate in this task. Significant effort will be involved in establishing the requirements for Automatic Mission Design Program and utilizing this program to plan missions. However, until this program is operational, Preliminary Mission Profiles must be generated, therefore, manpower is also allocated to this task.

    Operations manloading has been determined by the fact that both NASA & DOD will be operating MCC's and a high degree of automation will be implemented to minimize the number of personnel required after 1981. This will be accomplished by: utilizing Automatic Mission Design program for planning missions; Tug operations will be somewhat independent of ground control (autonomy level III); and service/maintenance reports provide the main input for post flight evaluation.

- Methodology: (continued)

Manpower has been assigned for each task in mission planning, flight control, evaluation and software. These are subdivided into non-recurring and recurring manpower. Paragraphs 6.4.4.1 through 6.4.4.14 contain task flow charts, schedule/manpower and task description. This manpower has been further divided into prior IOC and post IOC and is the input to costing in paragraph 6.4.5, where manpower and software word estimates are converted to dollar values.

To provide visibility into the manpower requirements, Figure 6.4.4-a shows the estimate for contractor in all categories. Graphs of NASA/Contractor, DOD/Contractor and total manpower for Government/Contractor are in Figures 6.4.4-b, 6.4.4-c, and 6.4.4-d.

<u>SUMMARY – CONTRACTOR MANPOWER</u>

FIGURE 6.4.4-a

1 FLT.

NON RECURRING		75	76	77	78	79	80	81
FLIGHT TEST (NASA)	MISSION PLANNING		1 1 1 2 2 2 3 3 3 4 4 4	4 4 4 4 4 4 3 3 3 3 4 4	2 2 2 3 3 3 4 5 5 5 6 6	6 6 6 6 6 6 4 4 4		
	FLIGHT CONTROL				1 1 2 2 3 3 3 3 3 4 4 5	7 9 10 11 13 14 21 24 31 33 40		
	FLIGHT EVALUATION			1 1 1 1 1 1	3 3 3 2 2 2 2 2 2 2 2 2	2 2 2 2 2 2		
	SUB TOTAL		1 1 1 2 2 2 3 3 3 4 4 4	— 4 5 5	6 6 7 7 8 8 9 10 10 11 12 13	15 17 18 19 21 22 25 28 35 37 40 38	36 32 22 8	
DDT&E (NASA)	MISSION PLANNING	6 8 12	13 15 17 17 19 19 18 16 18 18 16 16	16 — 16 15 16 18 22 26 32	38 44 54 58 60 62 62 60 60 60 58 58	51 49 47 43 39 35 27 27 23 20 17 17	17 25 27 36 46 46 46 44 44 42 38 36	34 34 30 26 21 21 17 12
	FLIGHT CONTROL			2 4 7 10 12 12	18 21 24 30 32 32 36 38 44 51 49 49	49 49 51 50 52 54 44 46 46 45 38 37	37 37 44 46 46 48 48 48 48 48 48 48	43 43 40 34 30 30 20 16 12 10 4 3
	FLIGHT EVALUATION			1 1 2 2 2 2	3 3 4 4 4 3 3 3 3 3 3 3	5 5 5 5 5 5 4 4 2 2 1 4	4 4 4 6 6 6 6 6 6 6 6 6	6 6 4 4 4 4 4 4 2 2 1
	SUB TOTAL	6 8 12	13 16 17 16 17 18 17 17 17 16 16 16	— 16 18 21 26 32 39 49	58 67 75 83 90 95 100 104 106 110 111 110	107 100 96 93 88 86 80 75 67 64 60 61	62 66 76 90 98 — 98 97 97 96 95 94	92 85 77 68 60 51 43 34 14 12 5 3
DDT&E (DoD)	MISSION PLANNING	4 4 4	4 4 4 5 6 7 7 8 —	— 8 — 8 9 9 9	8 — 8	10 12 14 16 18 18 17 17 17 —	—	— 17 15 15 13 13 12 12 8 8 4 1
	FLIGHT CONTROL				2 2 3 4 5 6 7 8 9 9 10 11	16 23 27 30 36 38 45 47 52 54 56 58	58 — 58 56	44 44 43 36 31 29 14 14 8 6 3 1
	FLIGHT EVALUATION			1 1 1	1 1 1 1 1 1 1 1 1 1 2	2	4 —	— 4 2 2
	SUB TOTAL	4 4 4	4 4 4 5 6 7 7 8 8 —	— 8 9 9 10	11 11 12 13 14 15 16 17 18 18 20 24	28 35 42 46 55 61 65 67 71 73 75 77	79 78 79 79 78 78 78 77	73 68 61 55 48 41 35 28 20 14 7 2
TOTAL CONTRACTOR		10 12 16	18 21 22 22 24 24 26 —	— 26 30 34 38 46 56 64	74 84 94 104 112 117 125 134 134 136 140 146	152 156 160 162 165 168 170 172 173 174 174 175	176 177 — 177 176 175 174 173 172	165 152 136 121 108 92 78 62 34 28 12 5

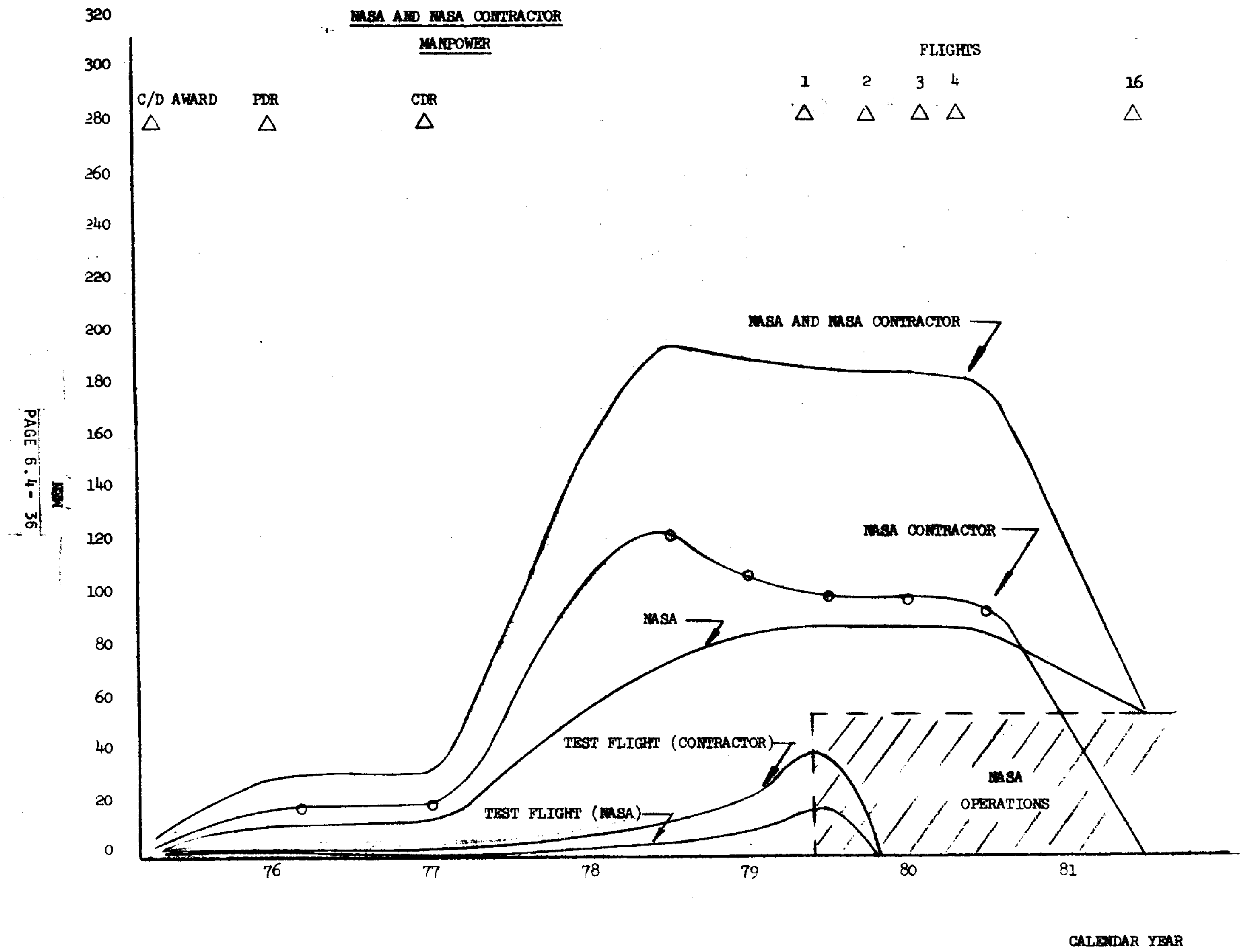

NASA AND NASA CONTRACTOR
MANPOWER
C/D AWARD
PDR
CDR
FLIGHTS
1
2
3
4
16
NASA AND NASA CONTRACTOR
NASA CONTRACTOR
NASA
TEST FLIGHT (CONTRACTOR)
TEST FLIGHT (NASA)
NASA
OPERATIONS
MEN
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
76
77
78
79
80
81
CALENDAR YEAR

FIGURE 6.4.4-b

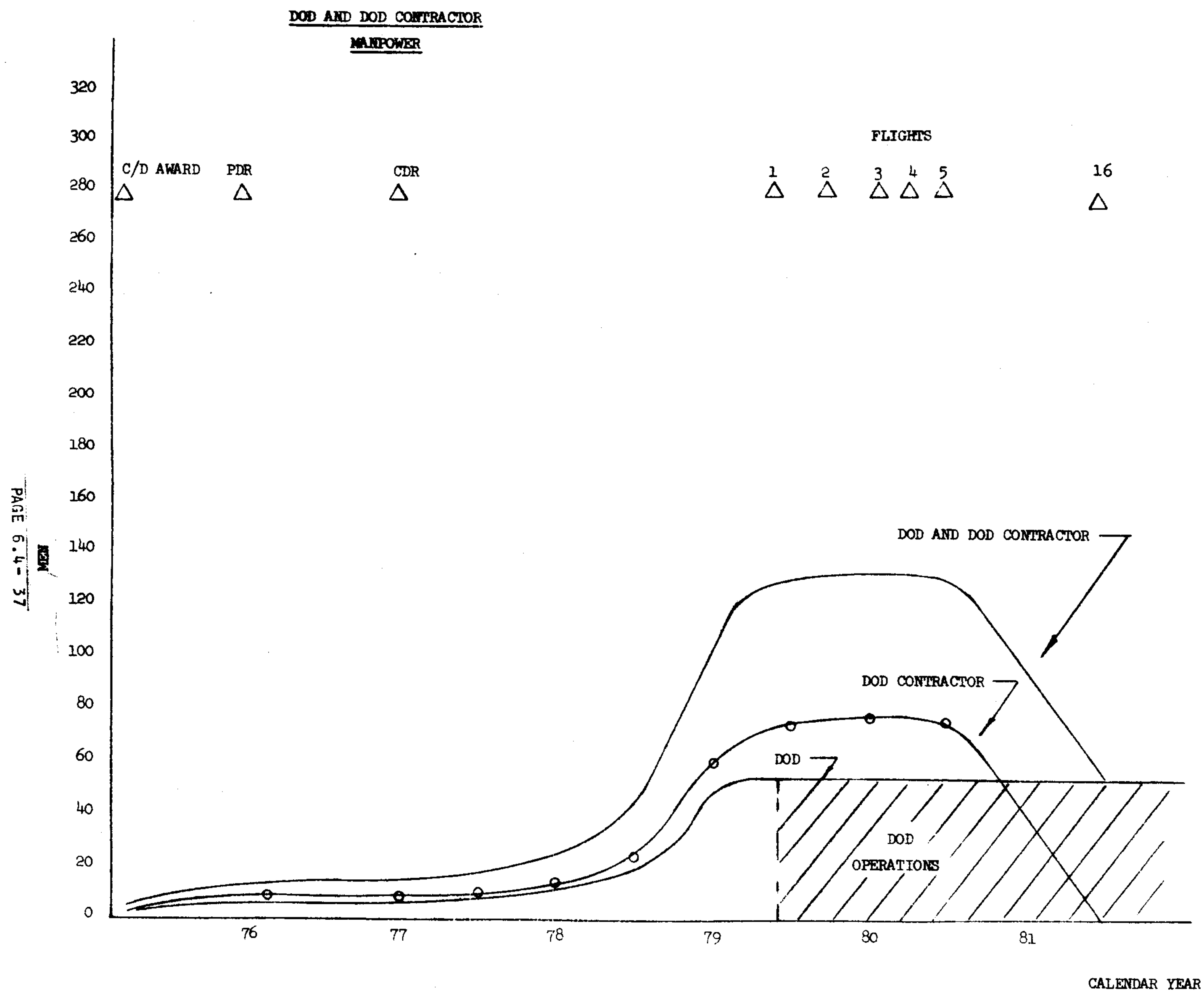

DOD AND DOD CONTRACTOR
MANPOWER
MEN
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
C/D AWARD
PDR
CDR
FLIGHTS
1
2
3
4
5
16
DOD AND DOD CONTRACTOR
DOD CONTRACTOR
DOD
DOD
OPERATIONS
76
77
78
79
80
81
CALENDAR YEAR

FIGURE 6.4.4-C

TOTAL MANPOWER

GOVERNMENT & CONTRACTOR

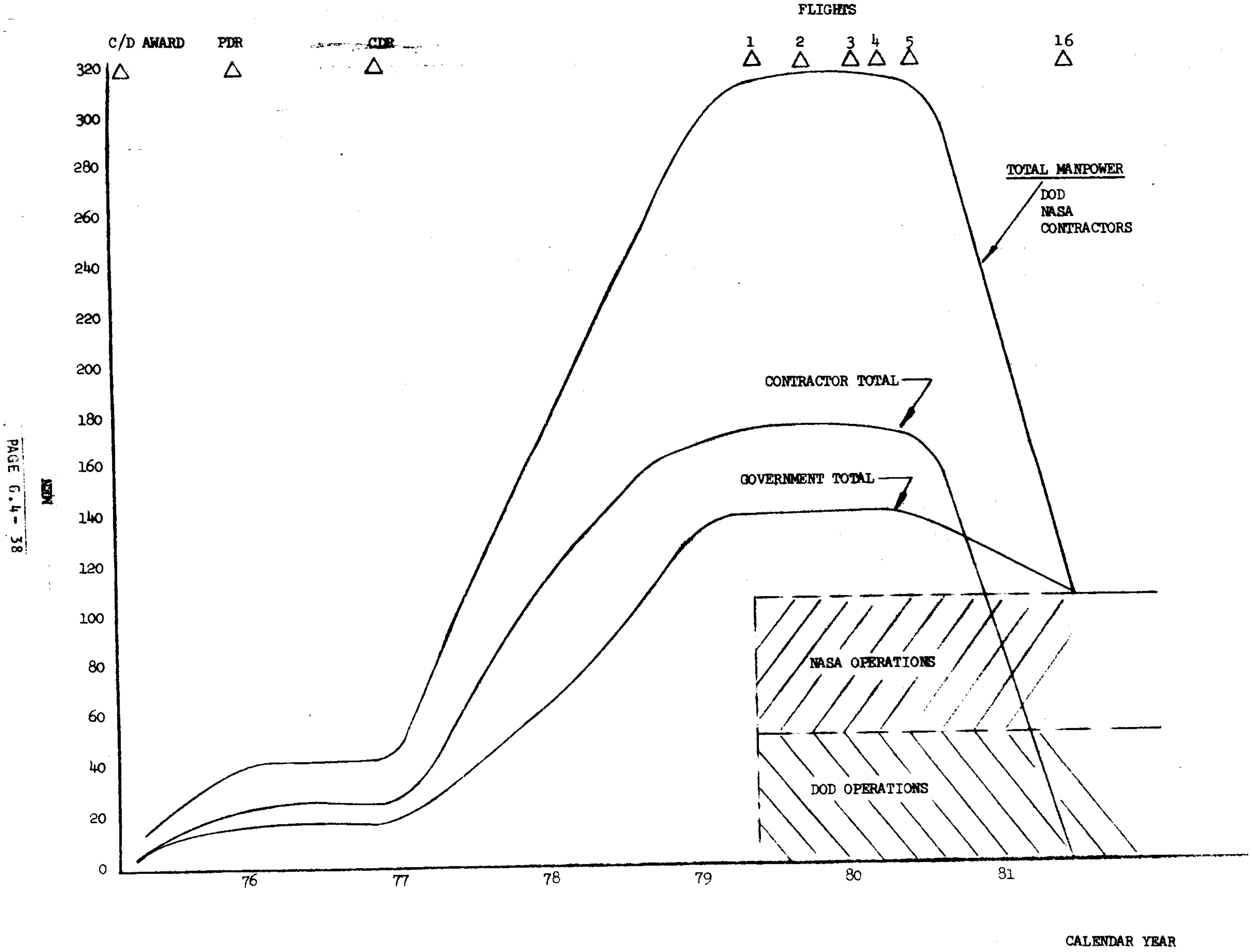
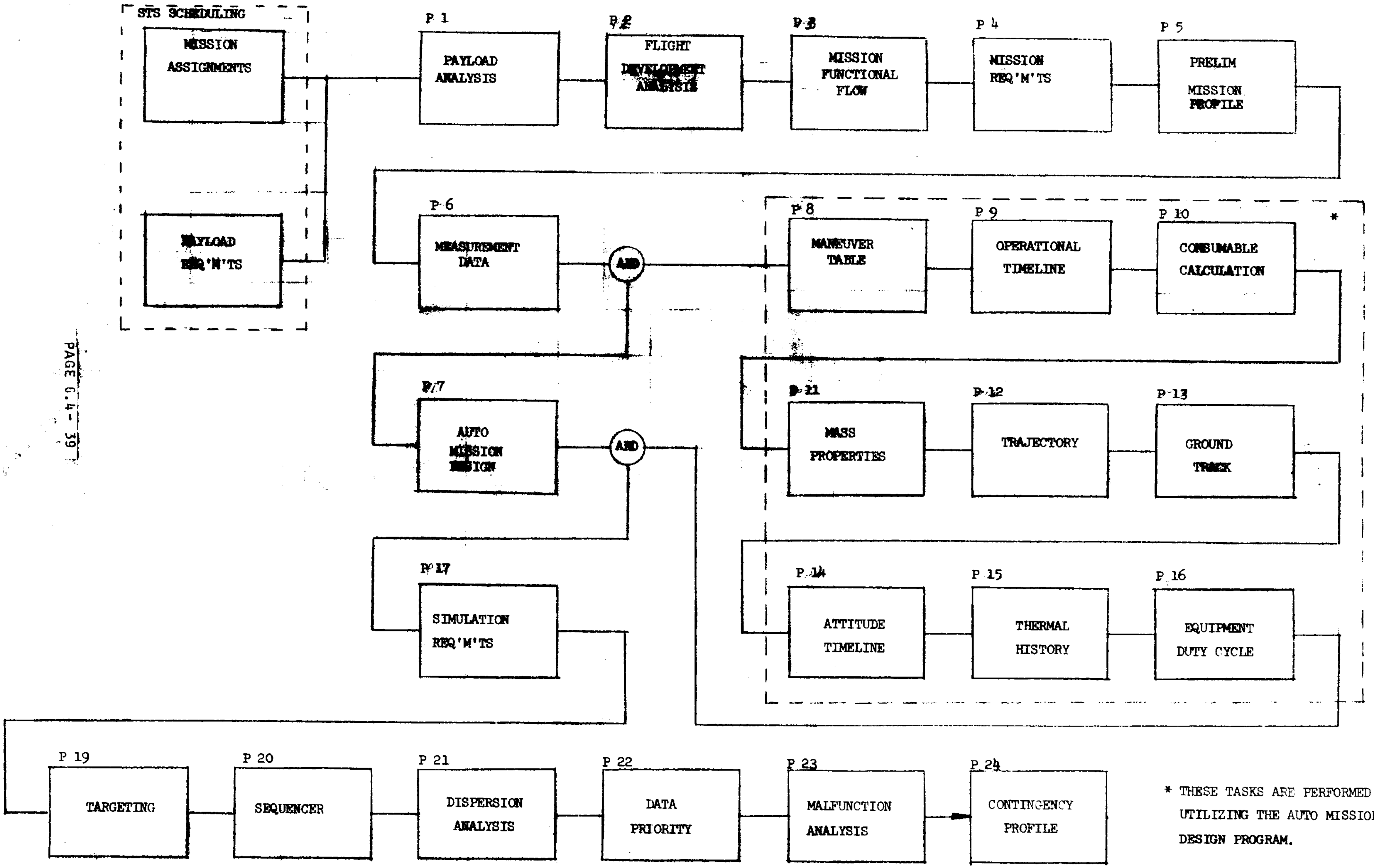


FIGURE 6.4.4-8

FLIGHT OPERATION WBS - 320-11 (NASA) NON RECURRING

FLIGHT PLANNING WBS 320-11-01 (NASA) FUNCTIONAL FLOW



* THESE TASKS ARE PERFORMED UTILIZING THE AUTO MISSION DESIGN PROGRAM.

FLIGHT OPERATIONS WBS 320-12 (DOD) NON-RECURRING

FLIGHT PLANNING WBS 320-12-01 (DOD) FUNCTION FLOW

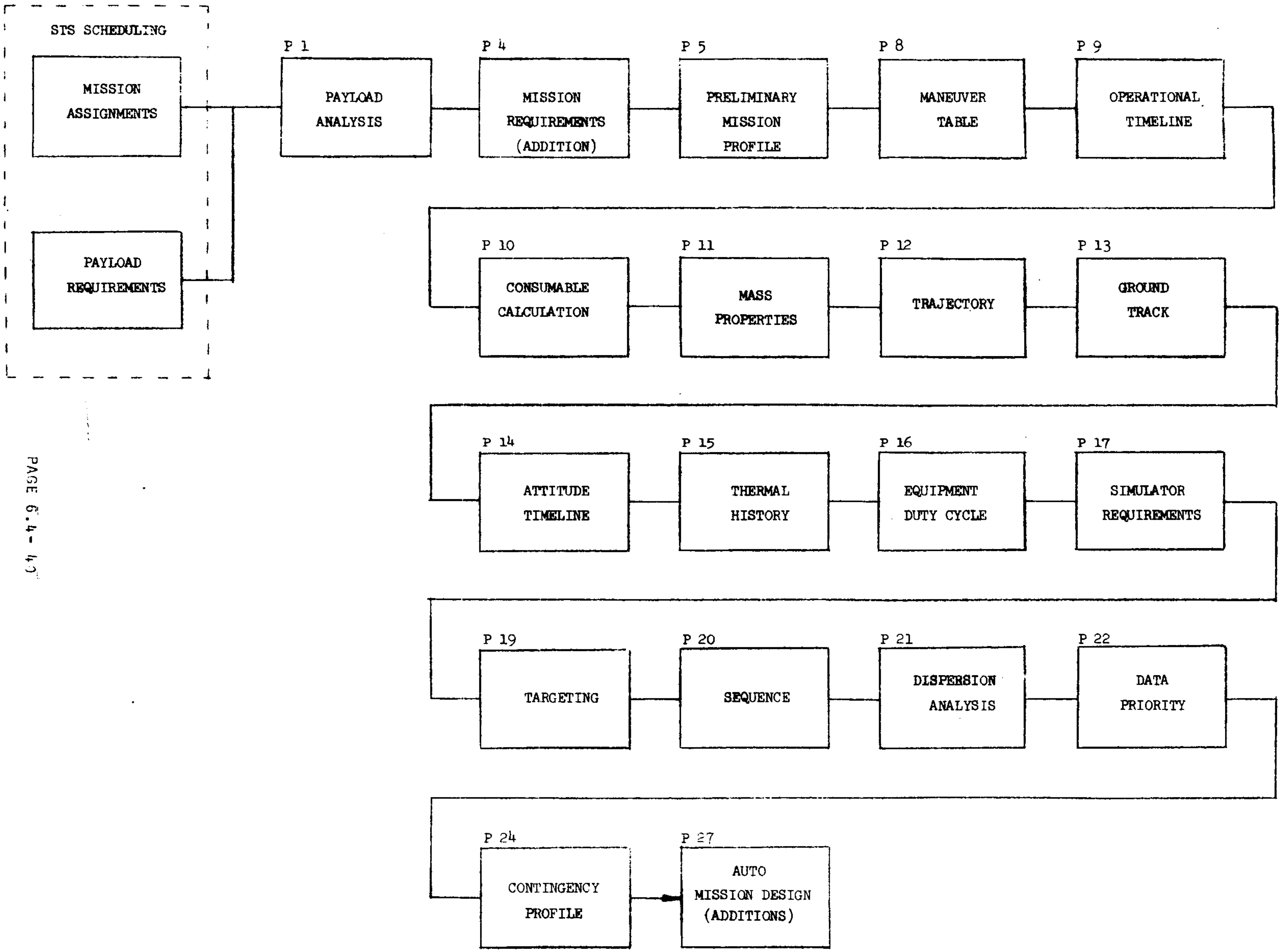


FIGURE 6.4.4.1-1

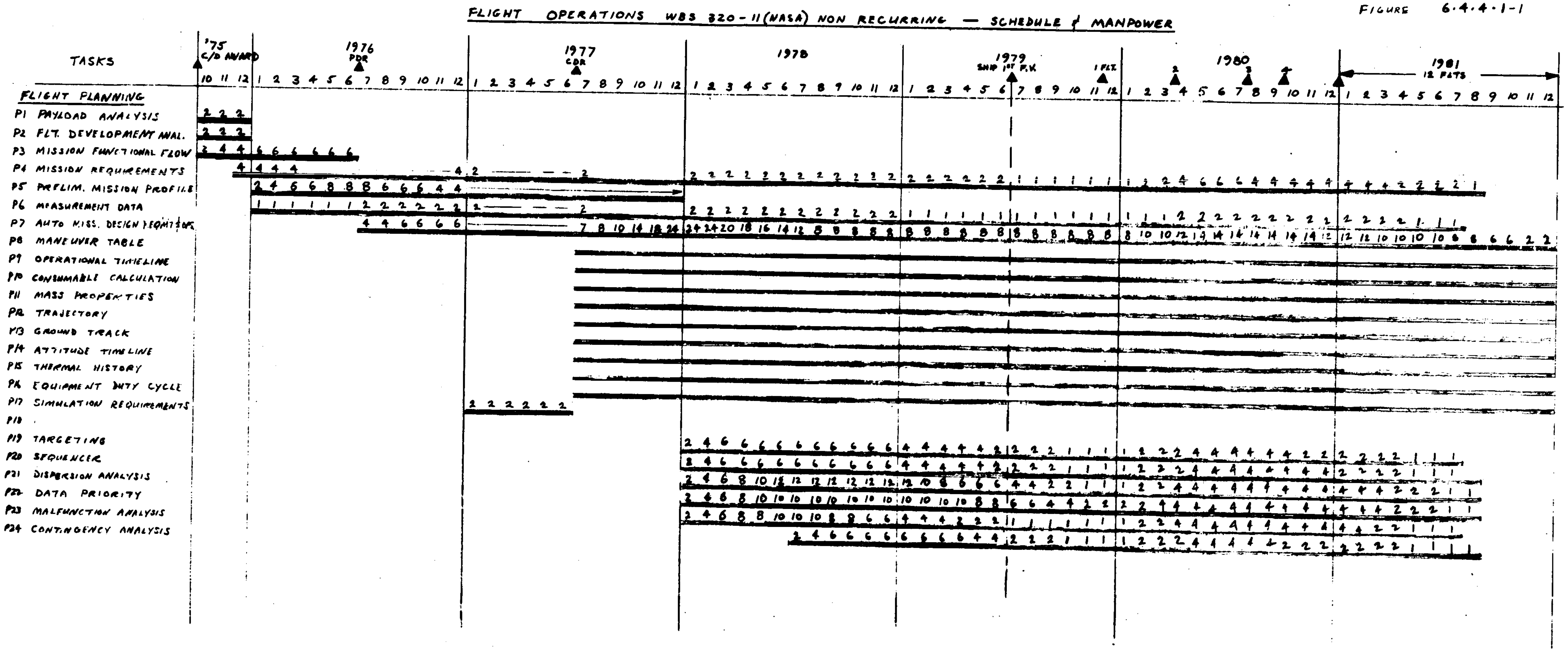
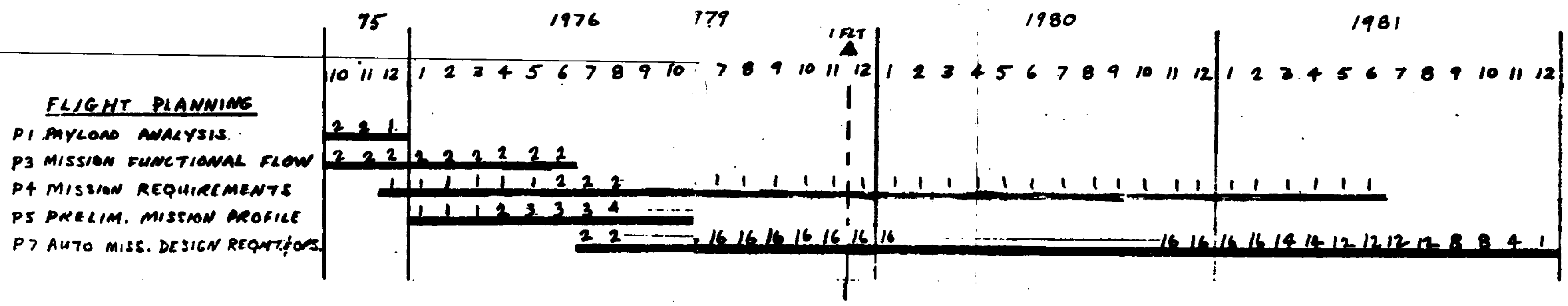


FIGURE 6.4.4.1-2

EDULE & MANPOWER



6.4.4.1 Task Description - Mission Planning

TASK

P1 Payload Analysis - This task comprises the effort required in analyzing the physical and mission characteristics of the payloads, comparing these data with the proposed Tug performance characteristics, Shuttle capabilities, and determining the optimum Tug design flight maneuvers, flight schedule, and manner of conducting the Tug missions.

P2 Flight Development Analysis - This task comprises the effort associated with evaluating the Tug performance requirements, the extent to which the development test programs provide verification and establishing the requirements for a flight test program to obtain performance data that can not be obtained by ground test. The analysis will result in a definition of the Flight Test Program, equipment, personnel and schedules.

P3 Mission Functional Flow - This task comprises the effort associated with generating a block diagram of major events required to perform each Tug mission. It provides the basis for defining the Tug system and subsystem requirements.

P4 Mission Requirements - This task comprises the effort associated with generating a Mission Requirements Document for each Tug mission. It will describe the mission purpose, mission objectives and detailed objectives. Each of the detailed objectives will be assigned a priority to facilitate alternate mission planning and post flight evaluation. Data requirements for each objective and its priority will be specified.

P5 Preliminary Mission Profile - This task comprises the effort associated with the generation of the preliminary mission analysis. It consists of sequences of events, consumables, and vehicle position in space as a function of mission time. This is the first step in developing the maneuver tables, operational timelines, and operational trajectories.

P6 Measurement Data - This task comprises the effort associated with the generation of a Measurement Requirements Document to provide the necessary data to size the airborne and ground support data handling equipments for the Space Tug. These data will define the measurement points, quantity, type and accuracy of transducers, signal conditioning and telemetry systems for Developmental Flight Instrumentation, Operational Instrumentation, and Ground Support Equipment. Normal operating, pre-launch and flight red line limits will be provided for each measurement.

P7 Auto Mission Design - This task comprises the effort associated with specifying the requirements for a mission design data base and associated computer program to facilitate mission planning, real time support and post flight evaluation by eliminating the routine calculations required to generate operational timelines and perform subsystems analyses.

An Auto Mission Design program will accept data requests generated by Engineering personnel and will rapidly supply tables of mission events, consumables depletion, equipment duty cycles, mass properties and other requested Engineering data for mission planning and as a reference for post flight evaluation. Parametric evaluations in the design of nominal and contingency missions will be possible with a minimum of clerical labor.

The program will provide for simultaneous printout of each of the parameters of interest as a function of mission time to permit each discipline to evaluate the performance of its subsystem.

It will be used to verify the ability of the Tug to perform all Government planned normal, backup, alternate and abort missions.

P8 Maneuver Tables - This task comprises the effort associated with the generation of maneuver tables. These consist of a sequence of maneuvers utilizing the propulsion systems depicting burn times, Delta-V, resultant vehicle velocity and orbital parameters for a specific vehicle configuration and mission. The data forms a basis for timeline, functional analysis, consumables history, and performance evaluation of Tug options. This task will utilize the Auto Mission Design Program.

P9 Operational Timelines - This task comprises the effort associated with generating an operational timeline for each Tug mission. It provides a sequence of mission events and event duration. The timeline identifies the times at which specific attitude maneuvers are required. This task will utilize the Auto Mission Design Program.

P10 Consumables Calculations - This task comprises the effort required in performing the calculations required to determine consumable utilization of each subsystem for each Tug configuration and each mission. This effort will utilize the Auto Mission Design Program which will print out a mission consumable summary listing consumables remaining as a function of mission time. A detailed consumables tabulation will be printed out for each subsystem as a function of mission time indicating the quantity consumed for each event or maneuver, the duration of the event or maneuver, the quantity used and the quantity remaining.

P11 Mass Properties - This task comprises the effort required in generating a time history of the vehicles weight, moments of inertia, products of inertia and center of gravity for each mission as a function of events that would cause a change in these parameters. This task will utilize the Auto Mission Design Program.

P12 Trajectories - This task comprises the effort associated with generating trajectories for each mission consisting of mission information such as vehicle position, attitude during powered flight, line of sight data, separation distances from orbiter and payload and burn times for the main propulsion system and kick stages. The design trajectories are used to establish Delta-V budgets, time for major events, number of main engine and APS burns and top level GN&C accuracy requirements. These will be assembled into a trajectory program for use with the Auto Mission Design Program which will be used to generate operational timelines and provide data as to sunlight conditions, tracking station coverage, etc.

P13 Ground Track - This task comprises the effort associated with the generation of ground track data and will result in a tabulation of acquisition and loss of signal and site telemetry and data processing capabilities for each Tug mission.

Ground tracks will be generated utilizing NASA/DOD space and ground networks available in the Tug time phase. This task will utilize the Auto Mission Design Program.

P14 Attitude Timeline - This task comprises the effort associated with the generation of data describing the roll, pitch and yaw of the Tug with respect to inertial and local attitude references for each mission event time. The data will form a basis for scheduling IMU alignments and establishing the correct vehicle orientation prior to burns and mission critical phases. The attitude timeline will provide an input to the thermal history below.

P15 Thermal History - This task comprises the effort associated with generating a history of when the Tug enters and leaves sunlight and the duty cycles of the Tug subsystems to determine the effects on the Tugs thermal balance. These data will be utilized by the Auto Mission Design Program to determine the thermal integrity of the vehicle as mission parameters are varied.

P16 Equipment Duty Cycle - This task comprises the effort associated with the generation of equipment duty cycles for each Tug mission. The effort will be facilitated by utilization of the Auto Mission Design Program.

P17 Simulation Requirements - This task comprises the effort associated with establishing the simulation requirements to verify that the Tug can perform its designated mission. The simulations required to verify the functioning of on-board computers and the Tug subsystems will be defined.

P18 Deleted

P19 Targeting - This task comprises the effort associated with the determination of the initial conditions and methods whereby the Tug vehicle will be maneuvered from point to point in space. The targeting for vehicle burns will be performed both by the on-board computer and the ground computers. The ground computer may provide the targeting parameters or act as a backup to verify the on-board solutions.

P20 Sequencer - This task comprises the effort associated with the determination of the sequence with which on-board computer operations will be performed. The task entails both systems analysis and a detailed programming effort.

P21 Dispersion Analysis - This task comprises the efforts associated with the generation and tabulation of error sources and magnitudes and a determination of their cumulative effects on the performance of the Tug mission. These errors include initial conditions, navigation and guidance systems component errors, propulsion system burn uncertainties, radar tolerances and all other uncertainties to ensure that the vehicle has a sufficient margin to successfully perform its mission considering a worst case error buildup.

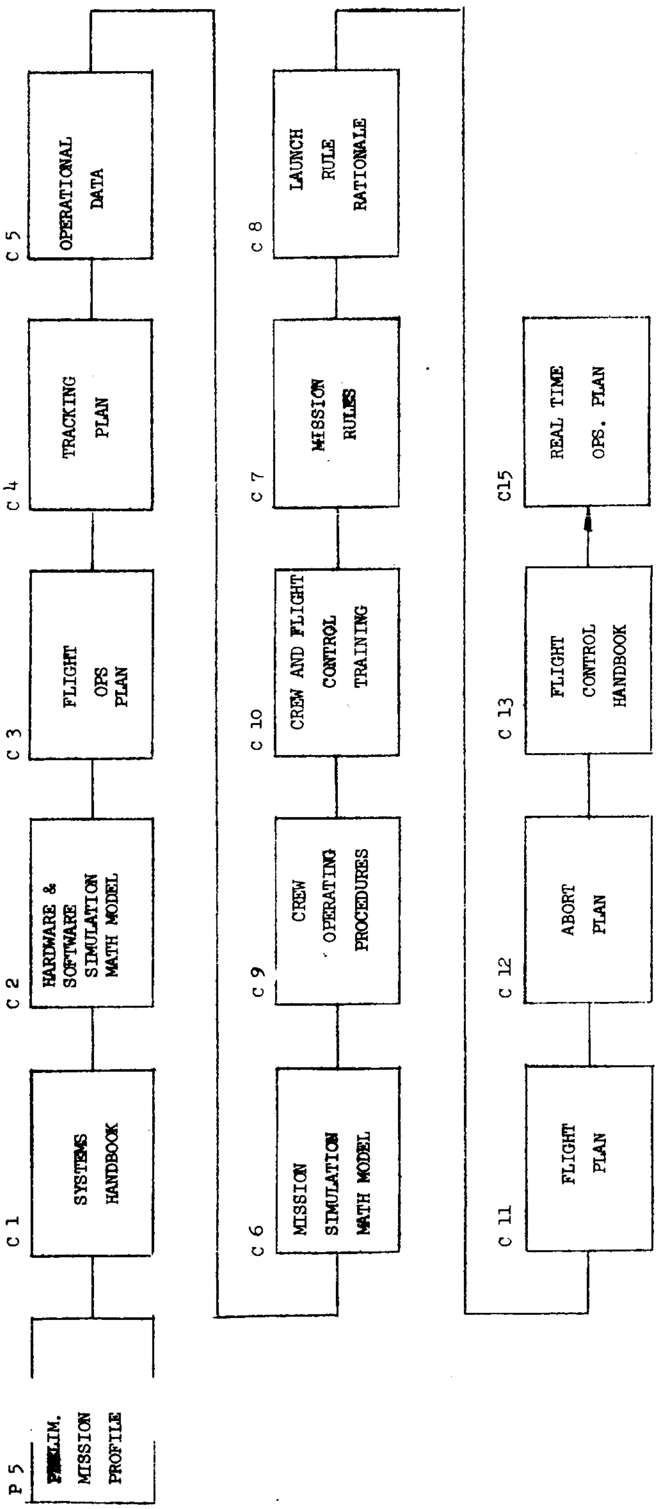
P22 Data Priority - This task comprises the effort associated with investigation of potential problem areas in the operation of the Tug mission and proposing a mission, hardware, software or procedural resolution. The issues considered are major involving crew safety or those having a significant effect on the program.

P23 Malfunction Analysis - This task comprises the effort associated with generating a Malfunction Analysis for the Tug vehicle utilizing the failure data, from the Failure Modes and Effects Analysis. Diagnostic and corrective action procedures will be generated for each failure to the level at which corrective action is possible either via ground commands or via the on-board Data Management system. Emergency procedures will be generated for failures that require immediate corrective action via the on-board system.

P24 Contingency Profile - This task comprises the effort associated with the generation of preliminary mission profiles to be utilized in the event a failure occurs during flight preventing the Tug from performing its primary mission or if a contingency mission has to be scheduled on short notice.

FLIGHT CONTROL WBS 320-11-02 (NASA) FUNCTIONAL FLOW

FLIGHT OPERATION WBS - 320-11 (NASA) NON RECURRING



FLIGHT OPERATIONS WBS 320-12 (DOD) NON-RECURRING

FLIGHT CONTROL WBS 320-12-02 (DOD) FUNCTION FLOW

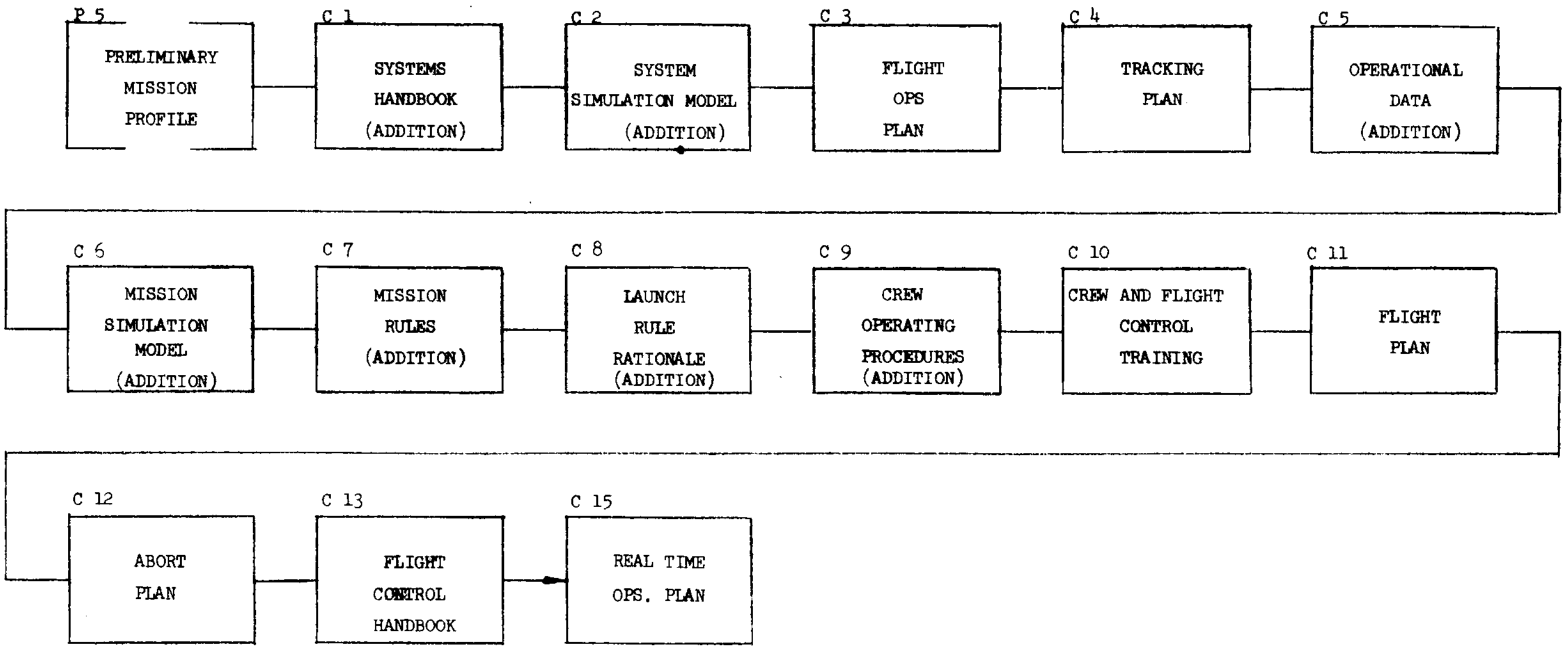


FIGURE 6.4.4.2-1

FLIGHT OPERATIONS WBS 320-11 (NASA) NON RECURRING - SCHEDULE & MANPOWER

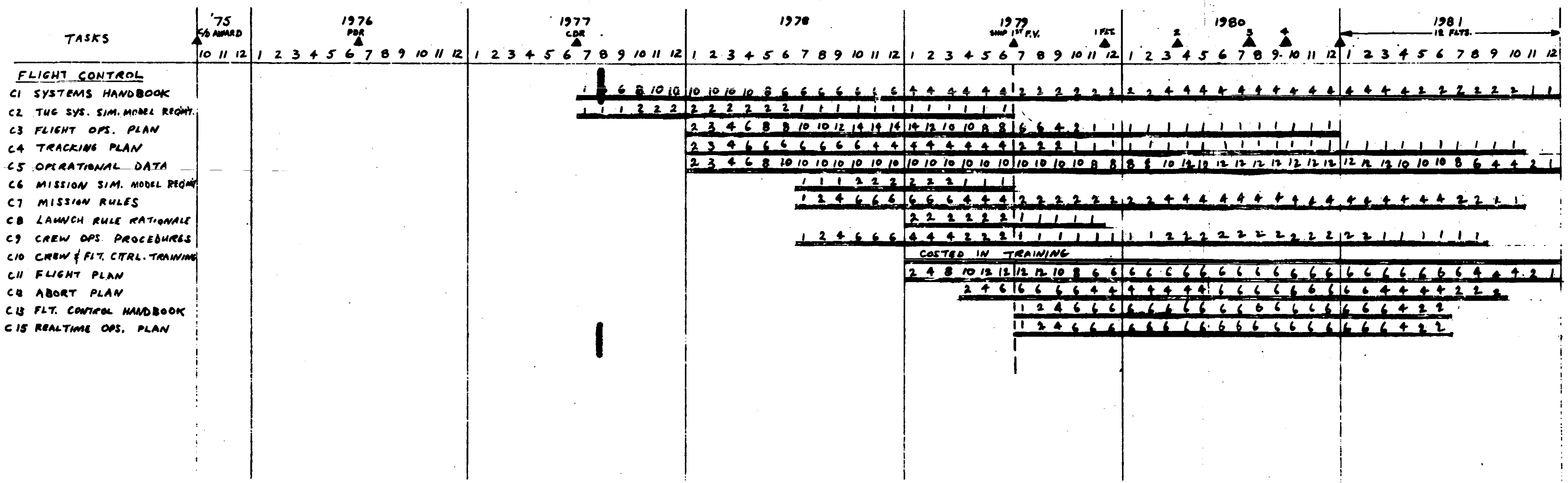
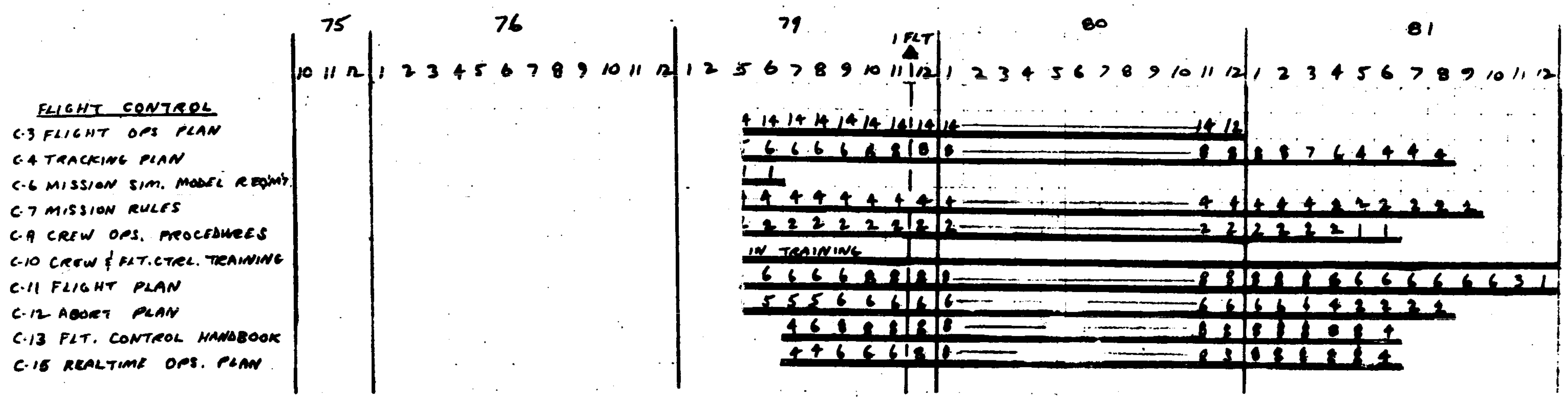


FIGURE 6.4.4.2-2

FLIGH SCHEDULE & MANPOWER



6.4.4.2 Task Description - Flight Control

TASK

C1 Systems Handbook - This task comprises the effort associated with generating the Systems Handbook, a document containing Tug system descriptions, drawings and supporting data intended for specialized use by flight controllers in real-time and near real time mission support operations and for ground checkout. The handbook contains a compilation of end-to-end functional flow diagrams for all of the Tug systems and describes the interface requirements between the Tug and other contractor equipments. The diagrams and related technical data contained in the handbook provide the necessary equipment detail to serve as a familiarization and trouble-shooting aid in simulations or flight tests and aids in the development of mission rules and workaround procedures.

C2 Hardware and Software Simulation Math Model - This task comprises the effort required to generate the requirements for math models representing the performance of the Tug hardware and software to permit digital simulation without the requirement to utilize the actual Tug equipments. The programs generated from the math models will provide the same input/output responses as the actual equipments.

C3 Flight Operations Plan - This task comprises the effort required to generate the flight operations plan, a document presenting an overall outline of the manner in which the Tug mission is to be supported and conducted by the contracting agency to accomplish the objectives of the mission. It contains support plans for each of the cognizant agencies delineating the responsibilities of each and establishes a chain of command for support of the mission.

The real time command philosophy is established and operational constraints, go-no go criteria and abort modes are stated and described and Telemetry capabilities and site locations as well as other data required to describe the top level description of support of the Tug mission are included.

C4 Tracking Plan - This task comprises the effort required to establish the tracking network location and characteristics required to support the Tug flight test and operational missions. Tracking coverage and data handling requirements will be specified for the life of the Orbiter/Tug system.

C5 Operational Data - This task comprises the effort required to develop the spacecraft Operational Data Book which will provide a single source for significant Space Tug nominal, off nominal, contingency performance and hardware constraints data. The data will be used for trajectory development, generation of Tug checkout procedures, consumables analysis, real time contingency mission planning and post flight data evaluation.

C6 Mission Simulation Math Model - This task comprises the effort required to generate the mission simulation math model a series of routines which permit a ground base computer to simulate a Tug mission in real-time and provide realistic outputs to control and display consoles for flight crew and mission support, personnel training and procedures development.

The model permits varying certain parameters to simulate off-nominal conditions.

C7 Mission Rules - This task comprises the effort required to generate mission rules a compilation of pre-planned procedural statements which provide flight control personnel with guidelines to expedite the decision making process in the event of failures, contingencies, or off-nominal operations during flight. The document id divided into two basic categories; general rules and specific rules. The first category defines the minimum capabilities which a subsystem has to provide to permit performing a particular mission phase. The second category describes a particular condition or malfunction of a subsystem the mission phase during which it occurs or is detected and a specific go or no go ruling and reconfiguration instructions.

C8 Launch Rule Rationale - This task comprises the effort to generate launch mission rules rationale for each Tug mission to provide an input to the launch rules by specifying pre-planned decisions when non-nominal conditions occur during the launch countdown and applicable pre-launch tests. The launch rules are effective from orbiter power-up to a few seconds prior to lift-off. Launch rules apply to all operational elements involved in the countdown and launch.

The document defines launch window periods, weather restrictions, Range Safety rules and redlines for the orbiter and Tug vehicle sub-systems. A section provides rules for Technical Support Operations including instrumentation and other non launch site support requirements.

C9 Crew Operating Procedures - This task comprises the effort associated with generating crew operating procedures consisting of detailed operating procedures performed by the orbiter flight crew in checkout, configuration, deployment and retrieval of the Space Tug for each Tug mission. The crew operating procedures document contains the Flight Crew Procedures which define the sequence of actions necessary for safe efficient equipment utlization under all operating conditions. Nominal and backup procedures are described and will form the basis for simulation and training for flight crew and mission support personnel.

C10 Crew and Flight Control Training - This task comprises the effort associated with generating a training plan which will establish the hardware and classroom, mockup and simulator training requirements necessary to familiarize Flight Crew and mission support personnel with the Tug subsystems and missions to ensure success of the Tug operations. It will define the type of personnel to be trained, training documentation required and establish criteria for success.

C11 Flight Plan - This task comprises the effort associated with developing the Flight Plan which schedules the operations required to fulfill the test objectives defined in the Mission Requirements Document. It contains a detailed timeline of mission events as a function of mission time listing all of the functions to be performed by the flight control personnel, consumables utilization curves, burn tables telemetry coverage and data required to monitor and support the flight.

C12 Abort Plan - This task comprises the effort associated with generating the Abort Plan an investigation of a number of alternate missions that could be utilized given a number of contingency situations that could arise in the course of a mission which would jeopardize mission success, mission requirements, rules and constraints. Alternate missions are described. The data presented include a description of the alternate mission, a timed sequence of events and data required such as telemetry coverage and ground tracks.

C13 Flight Control Handbook - This task comprises the effort associated with the preparation of a detailed Flight Control Handbook. This document will detail all of the information required by the Flight Controller and his personnel to perform the operational mission. It will contain detailed Tug command routines and procedures.

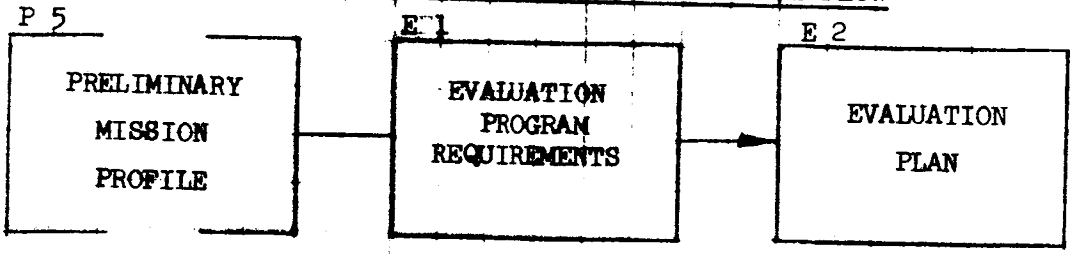
C15 Real Time OPS Plan - This task comprises the effort associated with the preparation of a real time operations plan. The plan will designate the responsibilities and functions of all personnel involved with Tug Real Time operations.

C16 Support Launch - This task comprises all of the efforts associated with support of a Tug mission launch.

C17 Real Time Mission Control - This task comprises all of the efforts associated with the ground control and support of a Tug mission.

C18 Operate Comm. Network - This task comprises all of the efforts associated with providing global tracking coverage for a Tug mission.

FLIGHT EVALUATION WBS 320-11-03 (NASA) FUNCTIONAL FLOW



FLIGHT EVALUATION WBS 320-12-03 (DOD) FUNCTIONAL FLOW

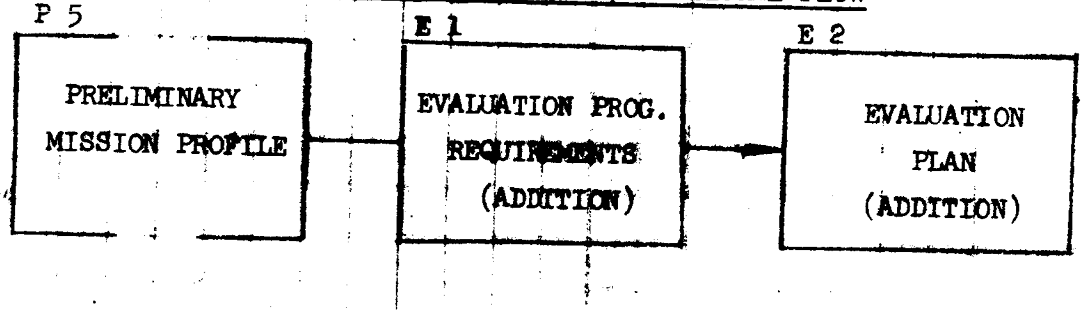


FIGURE 6.4.4.3-1

FLIGHT OPERATIONS WBS 320-11 (NASA) NON RECURRING - SCHEDULE & MANPOWER

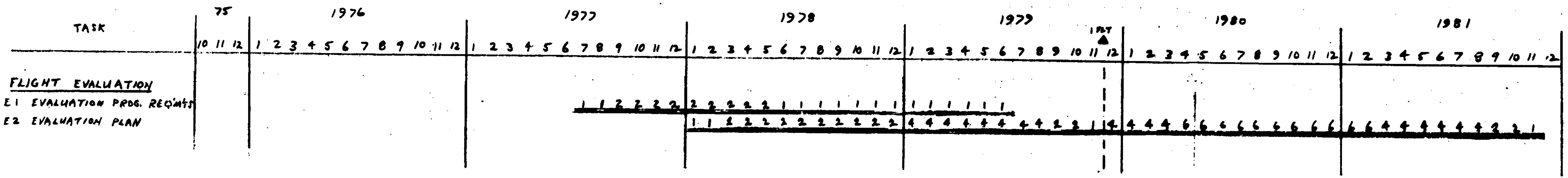
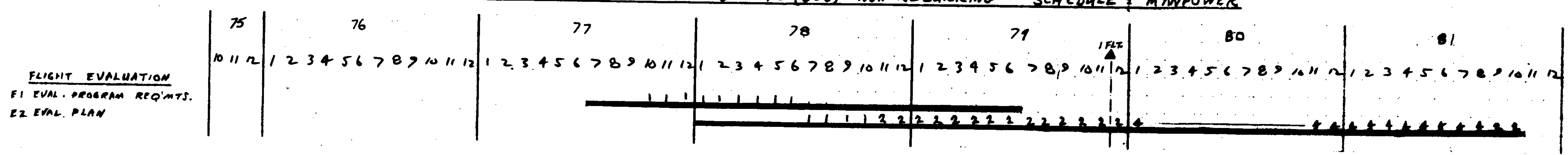


FIGURE 6.4.4.3-2

FLIGHT OPERATIONS WBS 320-12 (DOD) NON RECURRING - SCHEDULE & MANPOWER



6.4.4.3 Task Description - Flight Evaluation

TASK

E1 Evaluation Program Requirements - This task comprises the effort associated with establishing the requirements for the Tug Flight Evaluation Program. This will result in a definition of the software evaluation program requirements.

E2 Evaluation Plan - This task comprises the effort required to generate the flight performance evaluation plan a document which defines the requirements for a baseline analysis of the performance of the Tug. It is also intended to facilitate the formulation of a Performance evaluation report by compiling that information to be included in the report which lends itself to pre-flight determination. The document will contain:

(1) A section on evaluation requirements and success criteria for determination of vehicle performance characteristics, detailed objective satisfaction and significant mission event satisfaction.

(2) A general outline of the techniques and procedures to be employed for the resulution of flight problems.

(3) A synopsis of the data reduction support being provided for the evaluation effort.

E3 Post Flight Evaluation - This task comprises the effort after each mission associated with evaluating mission and subsystem performance of the Tug based on the requirements established by the evaluation plan.

The task involves analysis of the telemetry data and comparison with the previously established success criteria.

E4 Problem Resolution - This task comprises the effort after each mission associated with resolving flight anomalies utilizing the techniques and procedures specified in the Evaluation plan. A thorough analysis will be made of each flight anomaly and a hardware, software or procedural resolution developed for incorporation as a modification to ensure that the anomaly does not reoccur.

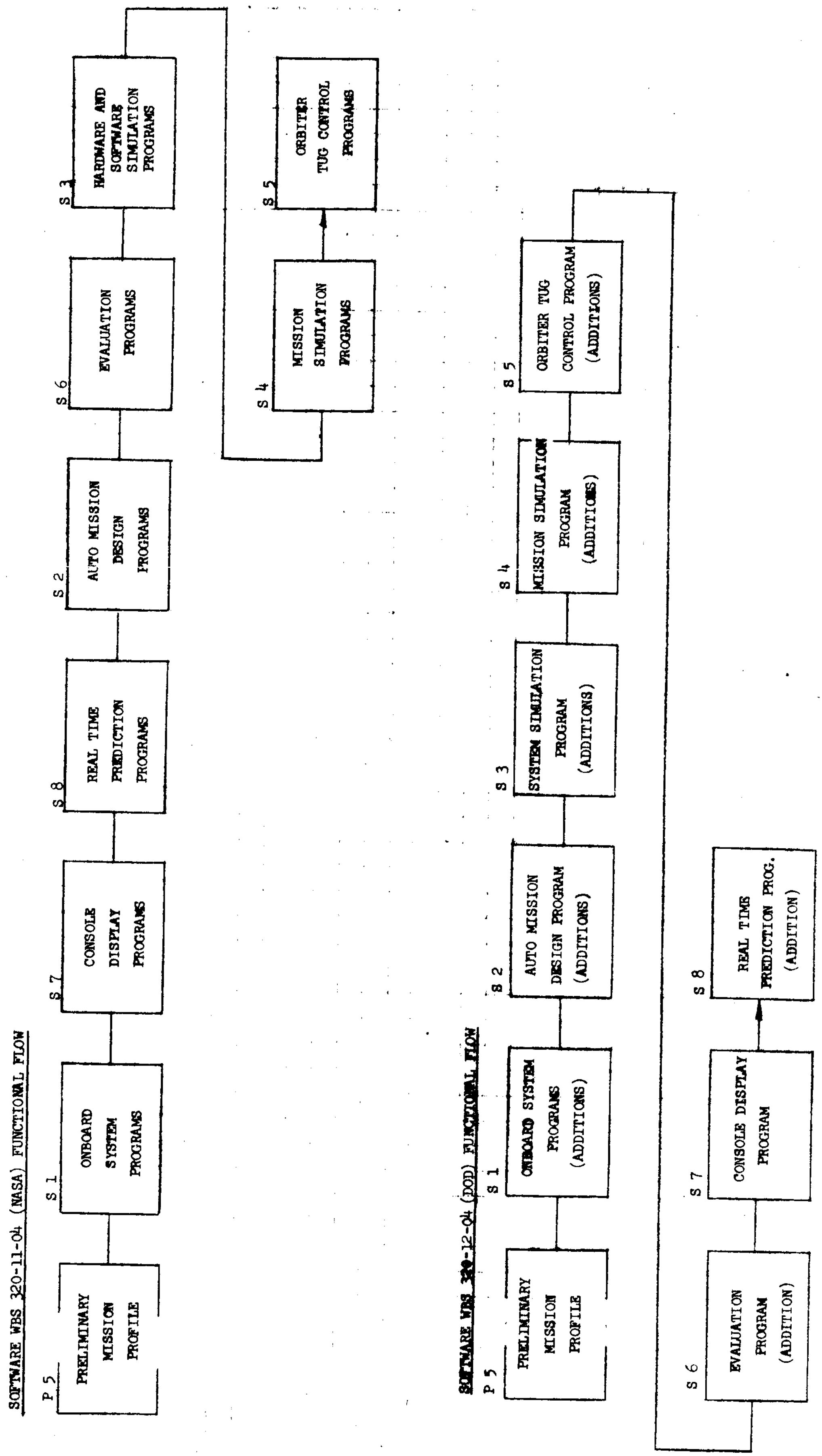
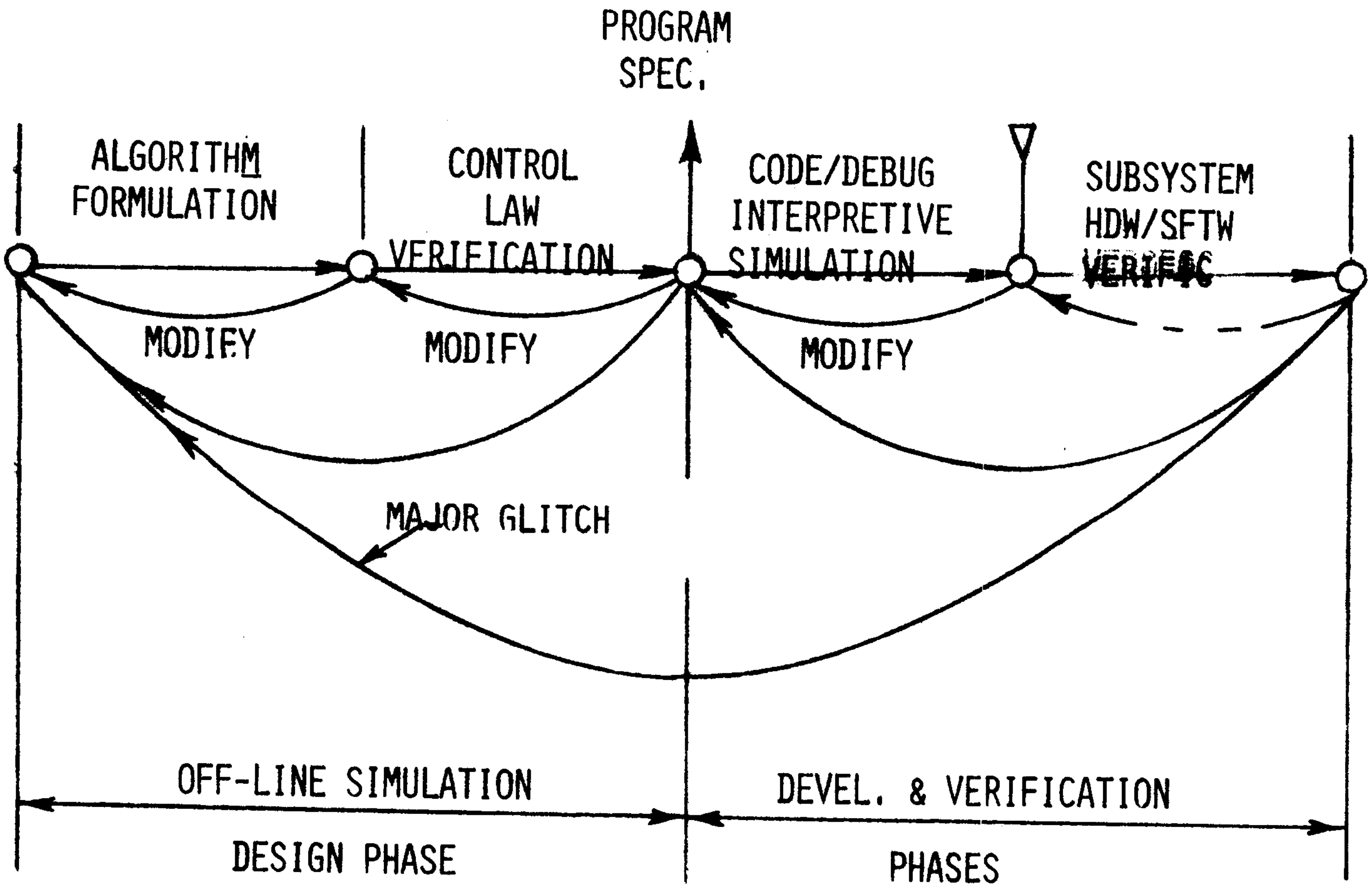

SOFTWARE WBS 320-11-04 (NASA) FUNCTIONAL FLOW
P 5
PRELIMINARY MISSION PROFILE
S 1
ONBOARD SYSTEM PROGRAMS
S 7
CONSOLE DISPLAY PROGRAMS
S 8
REAL TIME PREDICTION PROGRAMS
S 2
AUTO MISSION DESIGN PROGRAMS
S 6
EVALUATION PROGRAMS
S 3
HARDWARE AND SOFTWARE SIMULATION PROGRAMS
S 4
MISSION SIMULATION PROGRAMS
S 5
ORBITER TUG CONTROL PROGRAMS
SOFTWARE WBS 320-12-04 (DOD) FUNCTIONAL FLOW
P 5
PRELIMINARY MISSION PROFILE
S 1
ONBOARD SYSTEM PROGRAMS (ADDITIONS)
S 2
AUTO MISSION DESIGN PROGRAM (ADDITIONS)
S 3
SYSTEM SIMULATION PROGRAM (ADDITIONS)
S 4
MISSION SIMULATION PROGRAM (ADDITIONS)
S 5
ORBITER TUG CONTROL PROGRAM (ADDITIONS)
S 6
EVALUATION PROGRAM (ADDITION)
S 7
CONSOLE DISPLAY PROGRAM
S 8
REAL TIME PREDICTION PROG. (ADDITION)

Figure 6.4.4.4.4-2

SOFTWARE DEVELOPMENT FLOW GRAPH



- BASED ON - 38,000 WORD REQ'MT (HOL DEV'P BY SHUTTLE)
- EXCLUSIVE OF FACILITIES COSTS & OPERATING PERSONNEL

FIGURE 6.4.4.4-3

FLIGHT OPERATIONS WBS 320-11 (NASA) & -12 (DOD) NON RECURRING - SCHEDULE

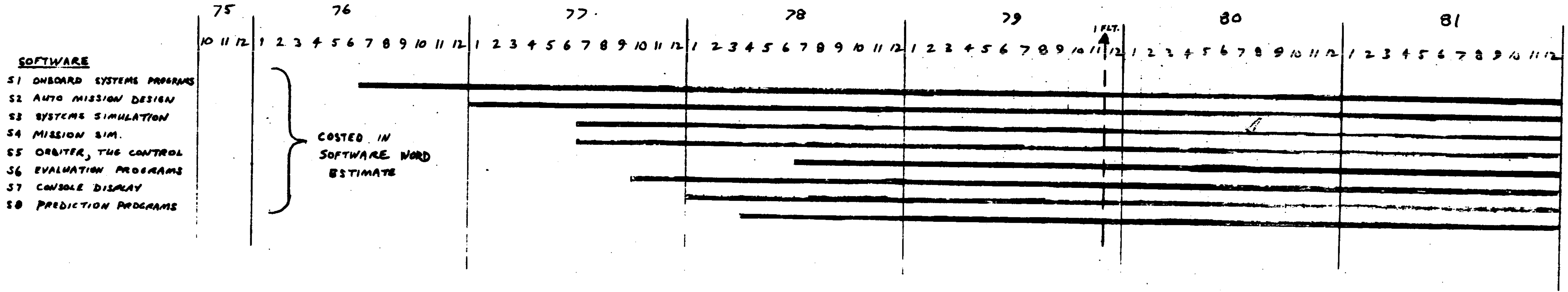


Figure 6.4.4.4.4-4

LEVEL I APPLICATIONS SOFTWARE ESTIMATE

PROCESSOR	EST.	RATIONALE
o EXECUTIVE		
- UPLINK/DWN LINK	300	AGS REQ'S 100 - LGC REQ'D 435
- NAV & GUIA. INIT'ZE	200	LGC P27 UPDATE = 268
- FIXED CONST'NT STORG	2000	AGS REQ'D 1000 - LGC REQ'D 2210
- SELF TEST	300	LGC REQ'D = 300
- EXECUTIVE LOGIC	5000	LGC REQ'D 5000
	9800	
o NAVIGATION		
- CALIBRATE & SERVICE	350	LGC REQ 282 (INCREASE FOR REDUND'CY)
- IMU ALIGN	900	LGC REQ'D 897 - INCLUDES STAR TABLE
- TRANSFORMATIONS	200	NAG
- STAR TR'K SERVICE	400	AOT SERVICE REQ'D 433
- IMU CHECK & MODE SWITCHING	600	LGC REQ'D 580
- POWERED FLT NAV	100	OPERATIONS COUNT OF SHUTTLE SOFTWARE LOGIC
- HORIZON SCAN PROCESSOR	800	ASSUMED AS COMPLEX AS STAR TRACKER
- HOR SCAN SERVICE	400	ASSUMED AS COMPLEX AS STAR TRACKER
- RENDEZVOUS NAV	500	LGC P20, P22 - 419
- ORBIT NAV	200	ASSUMED ADD-ON TO RENDZ NAV.
- RENDEZ'V SENSOR SEARCH	800	LGC RR SEARCH ROUTINE = 763
- R/R SERVICE	900	LGC ROUTINES REQ'D TO READ & MONITOR R/R
	6550	
o COASTING FLT NAV INTEGR	1500	LGC ORBIT INTEGRATION - 1507
- CONIC ROUTINES	1100	LGC REQ'S 1096
- OTHER NAV ROUTINE	400	LGC CALC. OF LAT, LONG. ETC.
	3000	

PROCESSOR	EST	RATIONALE
o GUIDANCE		
- VG CALC.	200	LGC
- CROSS PROPUCT STR	60	LGC
- TIME OF BURN CALC	100	LGC
- GUIDANCE	600	USES LGC ASCENT GUIDANCE
- SERVICER	1100	LGC GUIDANCE SERVICE ROUTINES
	2060	
o TARGETING & MISSION CONTROL		
- RENDEZVOUS	800	LGC COELLIPTIC SEQUENCE REQ'D 650
- OTHER	1000	WAG
- PRE THRUST ROUTINES	1000	LGC USES APPROX 1000 FOR THIS FUNCTION
	2800	
o CONTROL		
- AUTOPILOT	3500	LGC USES 3533
- SERVICE ROUTINES	1500	LGC USES 1534
	5000	
o S/S MONITOR/SERVICE		
- MPS	900	BASED ON LEVEL OF COMPLEXITY TO SERVICE AND MONITOR LM R/R
- EPS	900	
- APS	900	
- COMM	900	
- G&N	900	
	4500	
o MISSION SEQUENCING	4500	BASED ON THE LGC STARTUP ROUTINE AS TYPICAL SIZE OF AN EVENT ROUTINE (30 WORDS) & MISSION FUNCTIONAL FLOW THAT INDICATES 150 EVENTS AT LEVEL III.
TOTAL	38210	

Figure 6.4.4.4.4-5

6.4.4.4 Task Description - Software

TASK

S1 Onboard System Programs - This task comprises the effort required to generate detailed flight programs for loading the data management computer. These programs will perform the Guidance and Navigation calculations to control the Tug from its deployment until its return to the orbiter and will also supervise the on-board maintenance of the Tug.

S2 Auto Mission Design Programs - This task comprises the effort required to generate and verify the executive, data handling and computation programs required to perform task P7.

S3 Hardware and Software Simulation Programs - This task comprises the effort required to generate and verify the computer programs to implement the math models generated in task C2.

S4 Mission Simulation Programs - This task comprises the effort required to generate and verify the computer programs to implement the math models generated in task C6.

S5 Orbiter Tug Control Programs - This task comprises the effort associated with development of computer programs which will permit interchange of data and control commands between the orbiter and the Tug to permit the orbiter crew to assess Tug launch readiness.

S6 Evaluation Programs - This task comprises the effort required to generate and verify the computer programs required to perform task E3.

S7 Console Display Programs - This task comprises the effort required to convert telemetry data into a form required for presentation on the mission support consoles.

S8 Real Time Prediction Programs - This task comprises the effort to generate and verify the computer programs required to permit processing of real time telemetry data at regular intervals and to determine the extent to which the Tug is meeting its mission and subsystem requirements and extrapolate the data to indicate trends requiring possible corrective action.

VEHICLE TEST WBS 320-08 NON RECURRING (1 FLT. ONLY)

FLIGHT TEST OPERATIONS WBS 320-08-04 (NASA) FUNCTIONAL FLOW

FLIGHT PLANNING

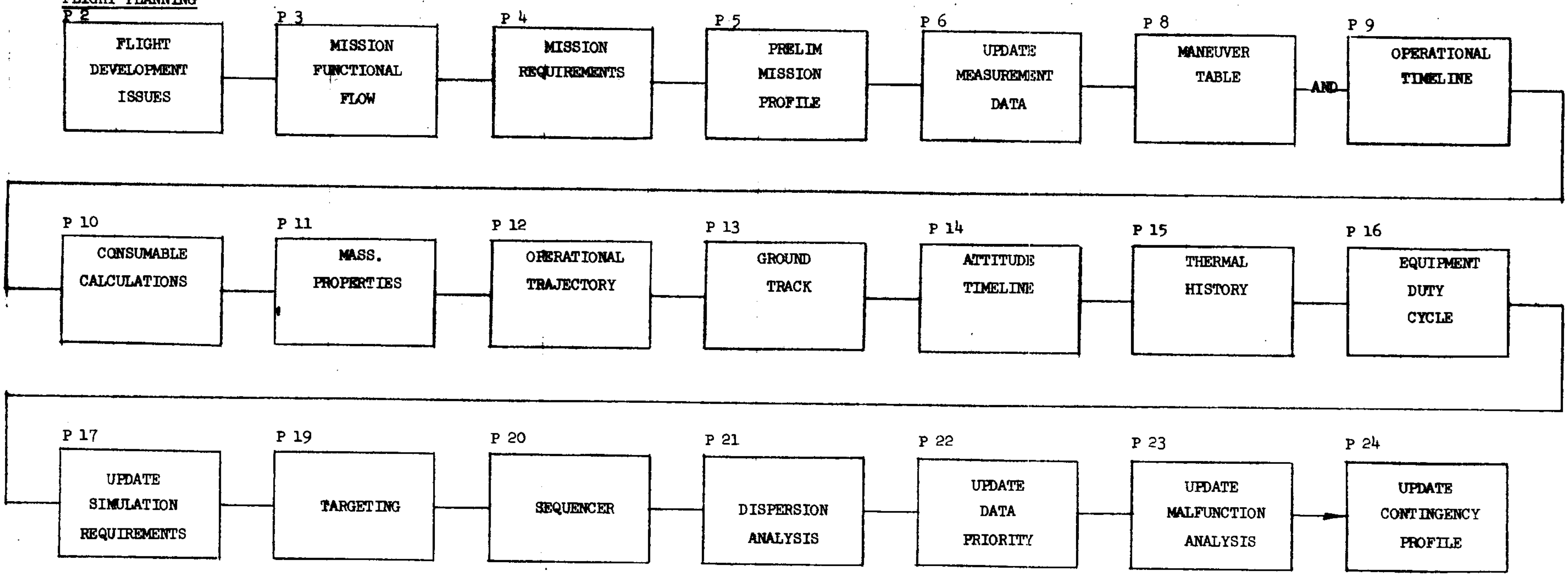
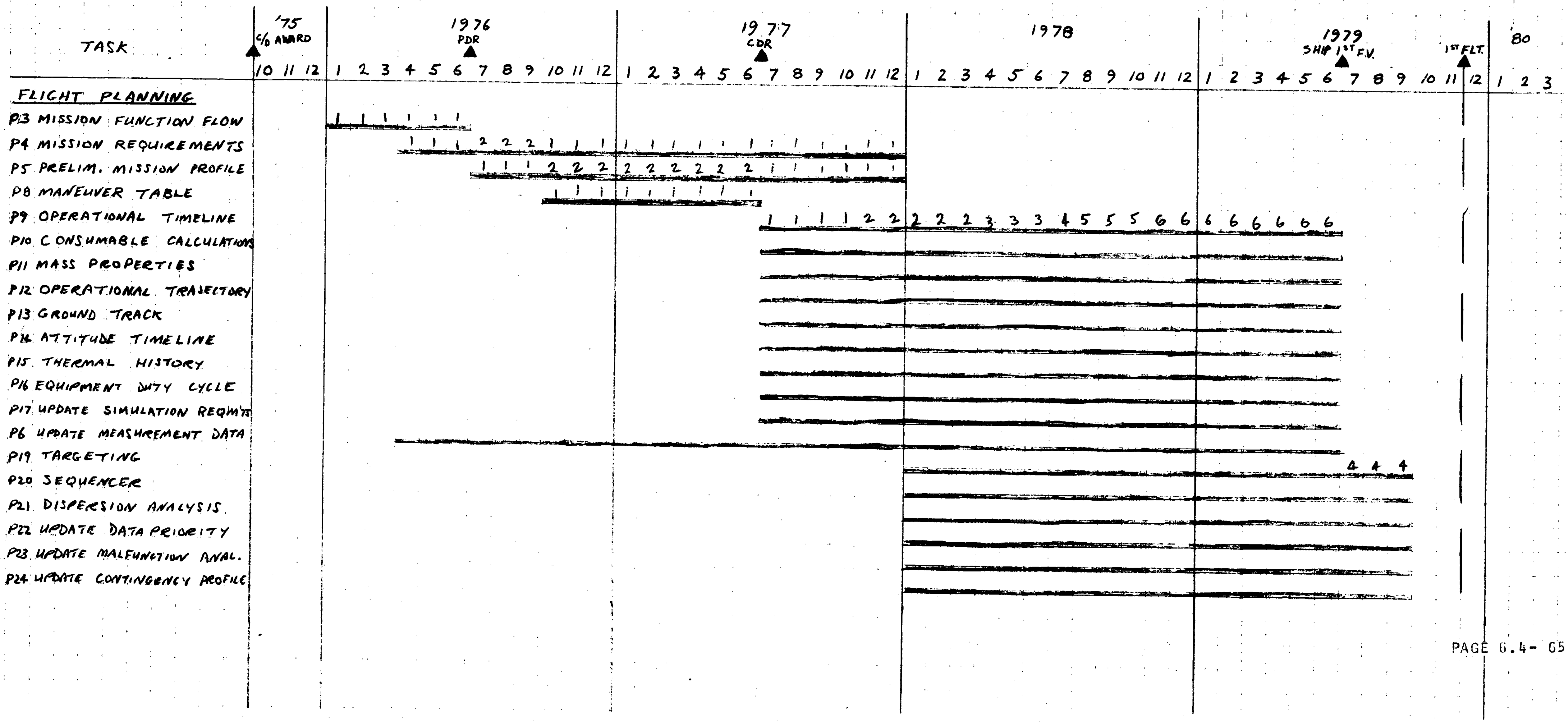


FIGURE 6.4.4.5-2

FLIGHT TEST OPERATIONS WBS 320-08-04 (NASA) NON RECURRING



VEHICLE TEST WBS 320-08 NON RECURRING (1 FLT. ONLY)

FLIGHT TEST OPERATIONS WBS 320-08-04 (NASA) FUNCTIONAL FLOW

FLIGHT CONTROL

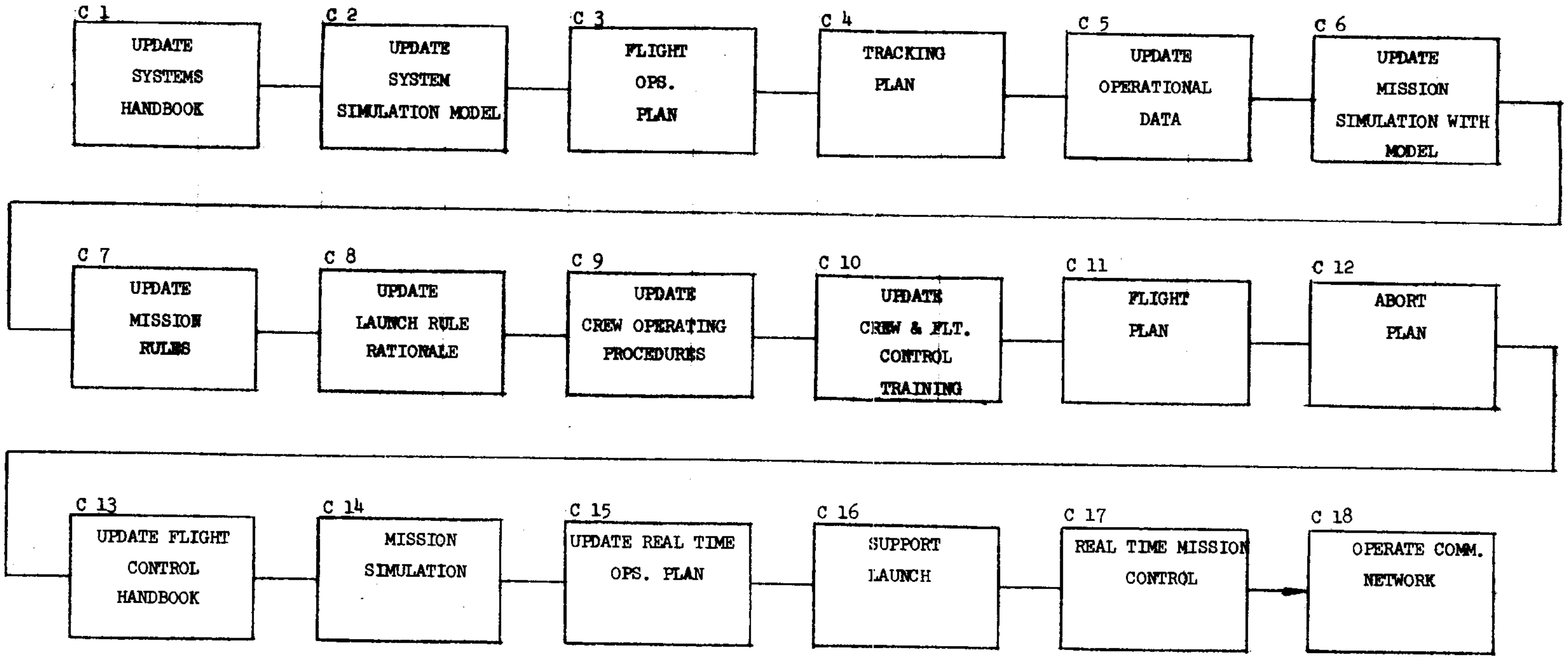
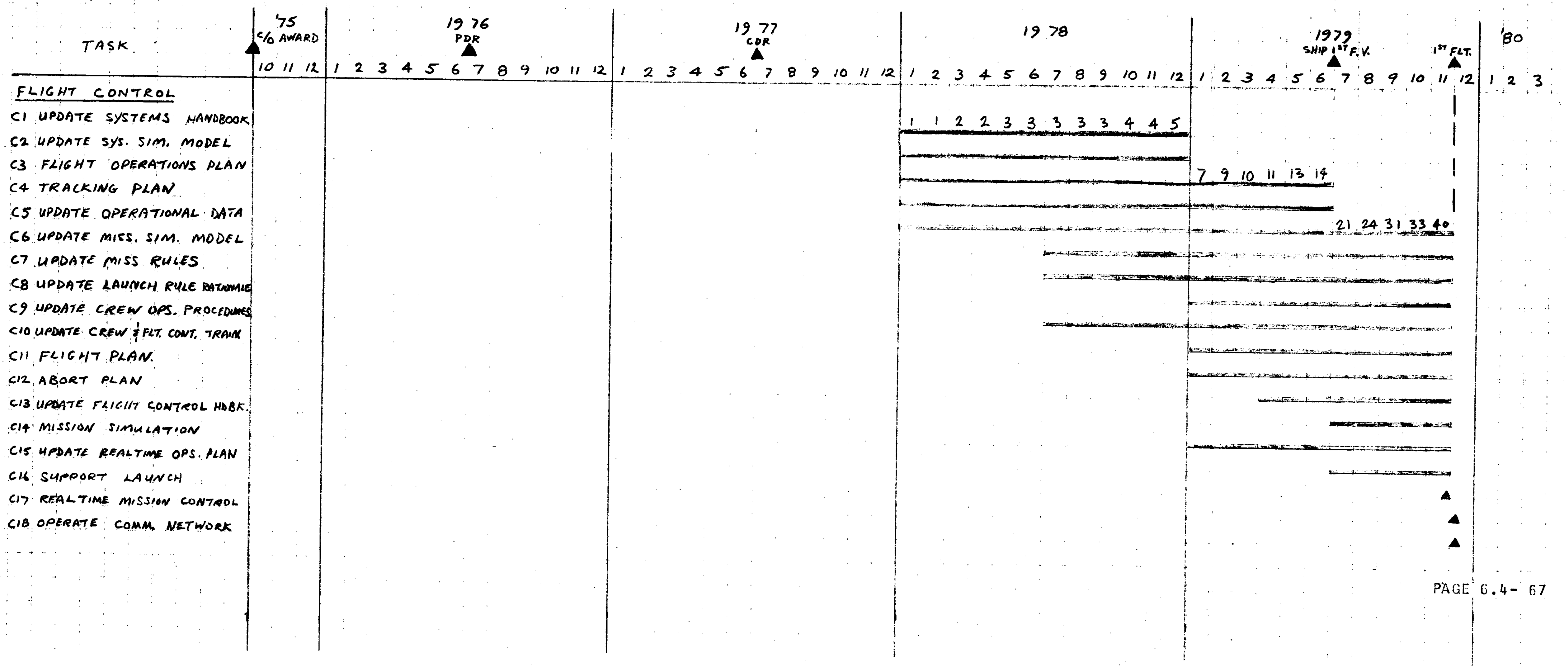


CHART 6.4.4.6-1

FLIGHT TEST OPERATIONS WBS 320-08-04 (NASA) NON RECURRING



FLIGHT TEST OPERATIONS WBS 320-08-04 (NASA) FUNCTIONAL FLOW

FLIGHT EVALUATION

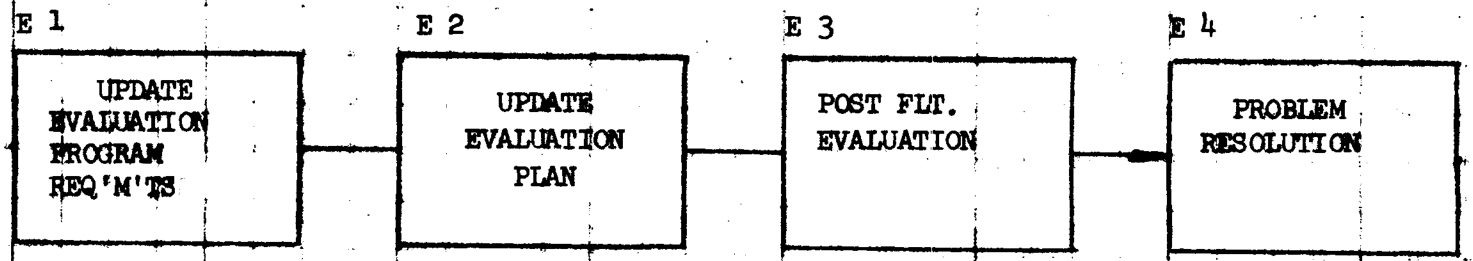
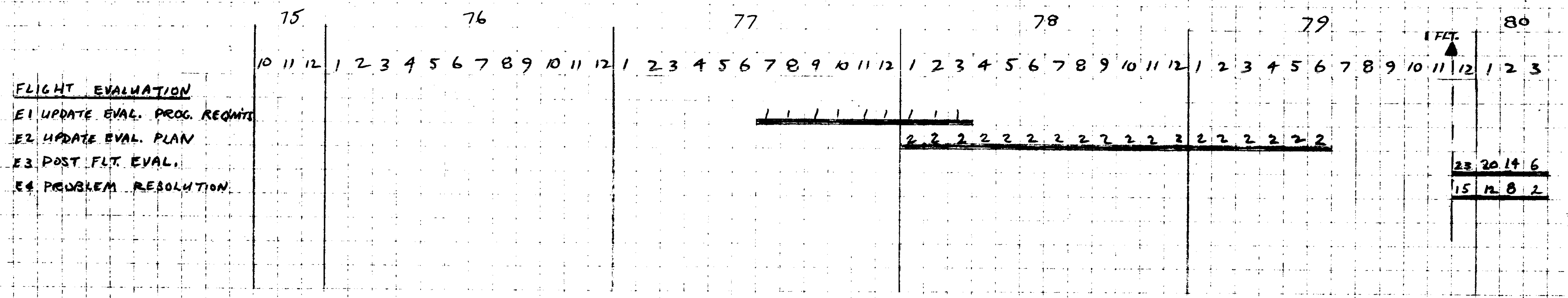


FIGURE 6.4.4.7-2

FLIGHT TEST OPERATIONS WBS 320-08-04 (NASA) NON RECURRING



FLIGHT TEST OPERATIONS WBS 320-08-04 (NASA) FUNCTIONAL FLOW

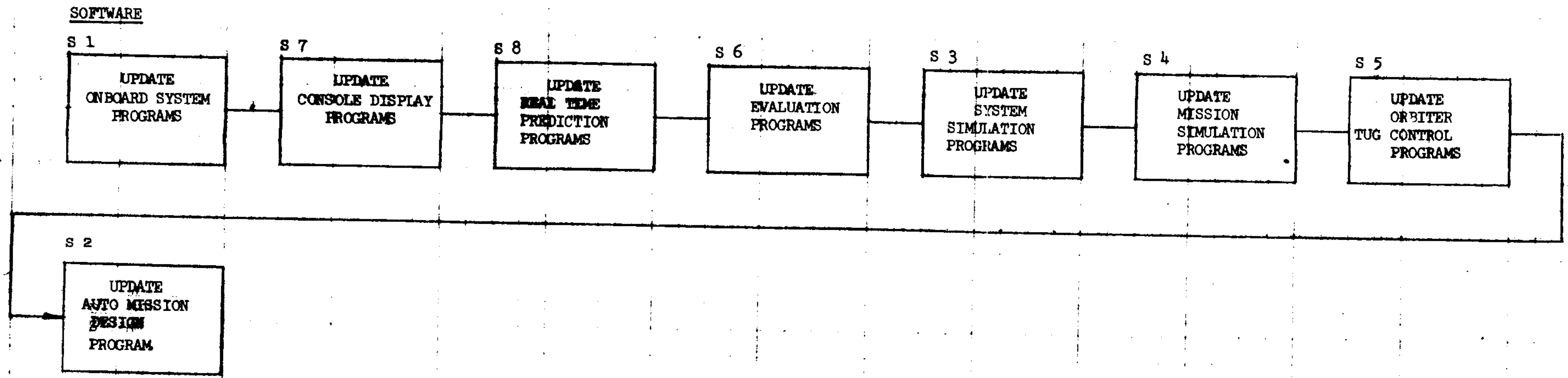
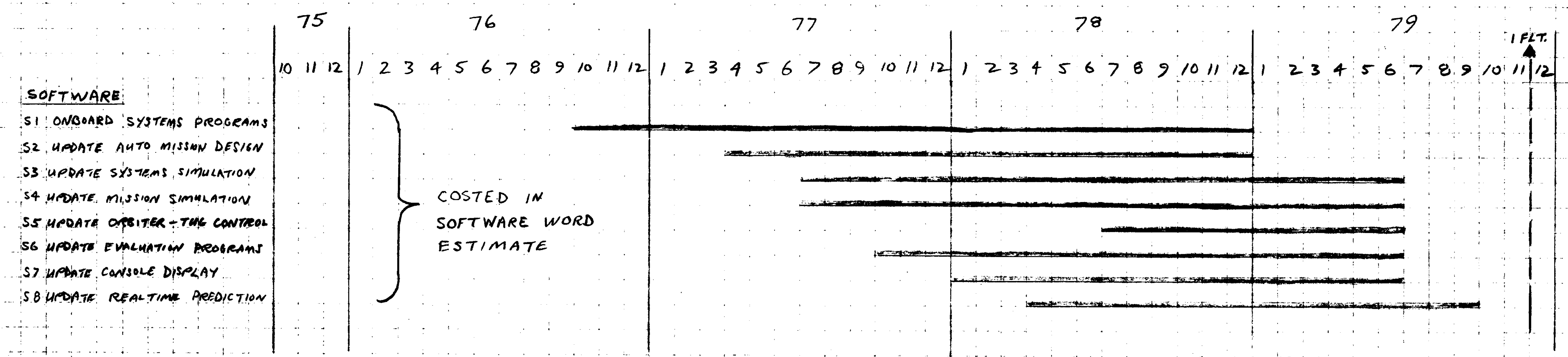


CHART 6.4.4.8-1

FIGURE 6.4.4.8-2

FLIGHT TEST OPERATIONS WBS 320-08-04 (NASA) NON RECURRING



FLIGHT OPERATIONS CONTROL WBS 320-07-04 (NASA) 320-07-05 (DOD) NON-RECURRING

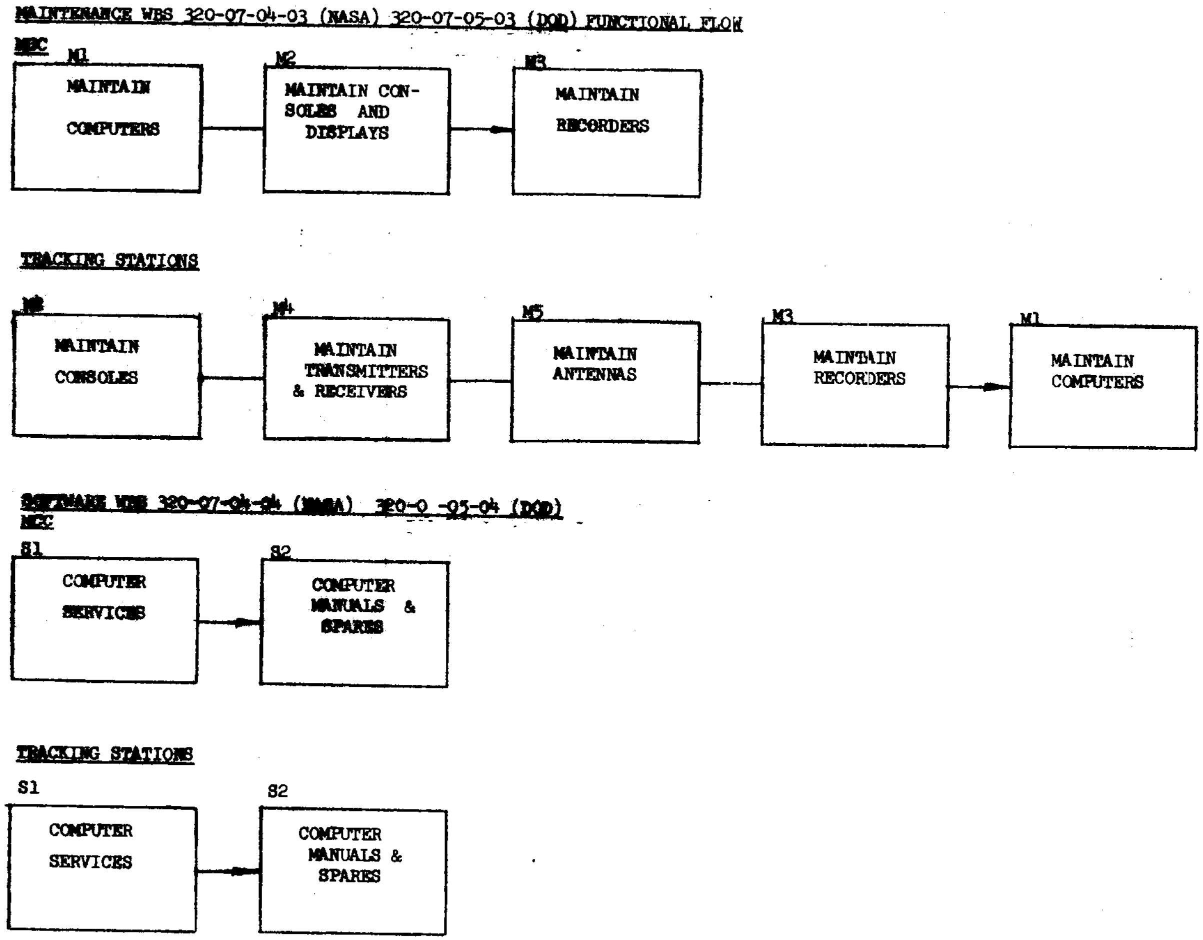
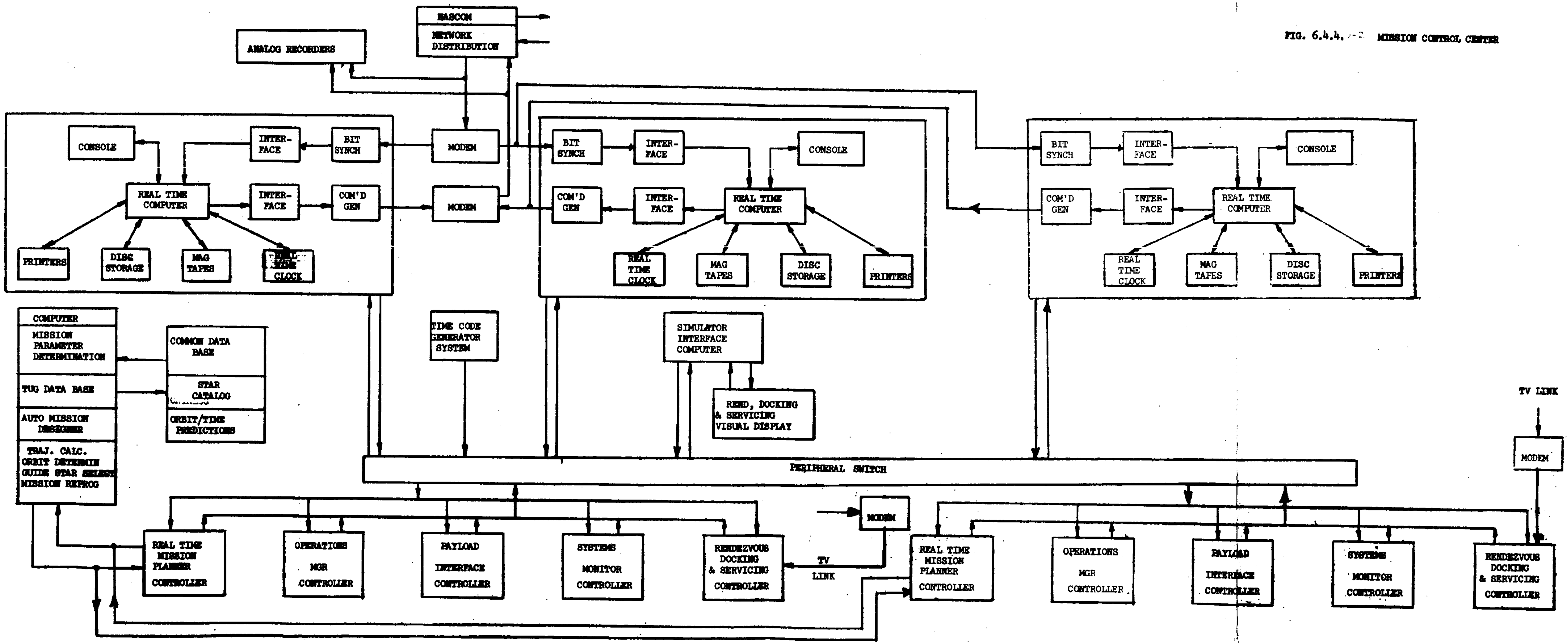
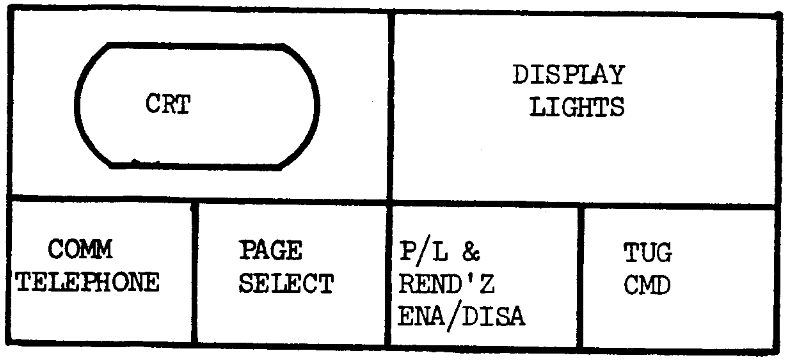


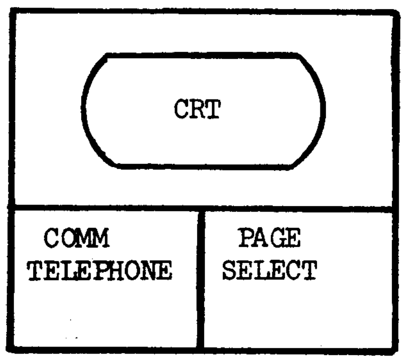
FIG. 6.4.4.-2 MISSION CONTROL CENTER



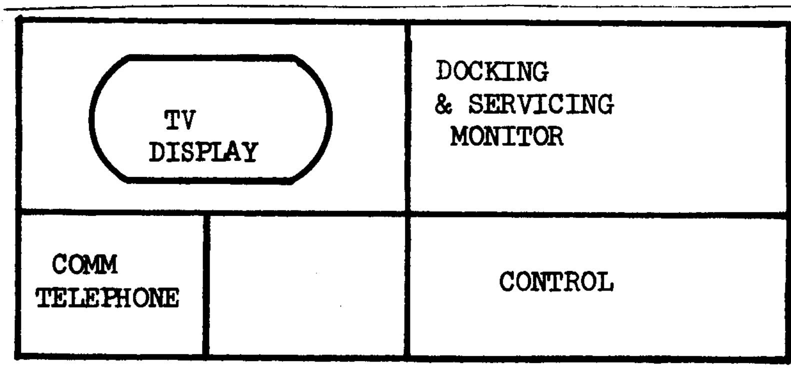
SYSTEMS CONTROLLER



OPERATIONS MANAGER

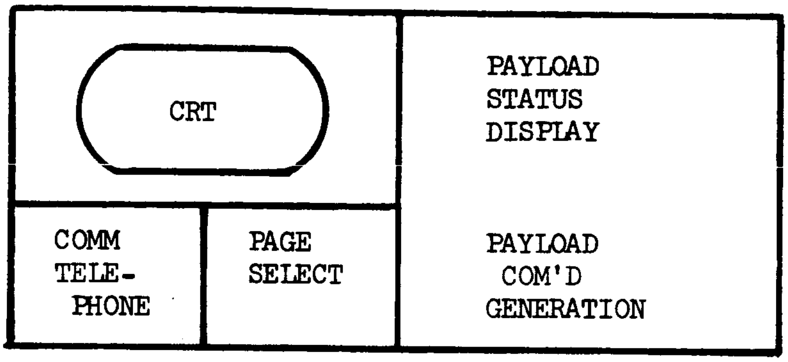


RENDEZVOUS, DOCKING & SERVICING CONTROLLER



PAYLOAD INTERFACE & EXPERIMENT CONTROLLER

CRT DISPLAY
PAGE SELECT KEYBOARD
COMM TELEPHONE BOX
P/L COMMAND GENERATION KEYB'D (THROUGH SYST. CONTROLLER)
P/L STATUS DISPLAY



REAL TIME MISSION PLANNER

CRT DISPLAYS
PAGE SELECT KEYBOARD
MISSION STATUS DISPLAY-LIGHTS
COMM TELEPHONE BOX
DATA REQUEST PANEL TO MISSION PARAMETER COMPUTER
DATA INPUT PANEL TO MISSION PARAMETER COMPUTER

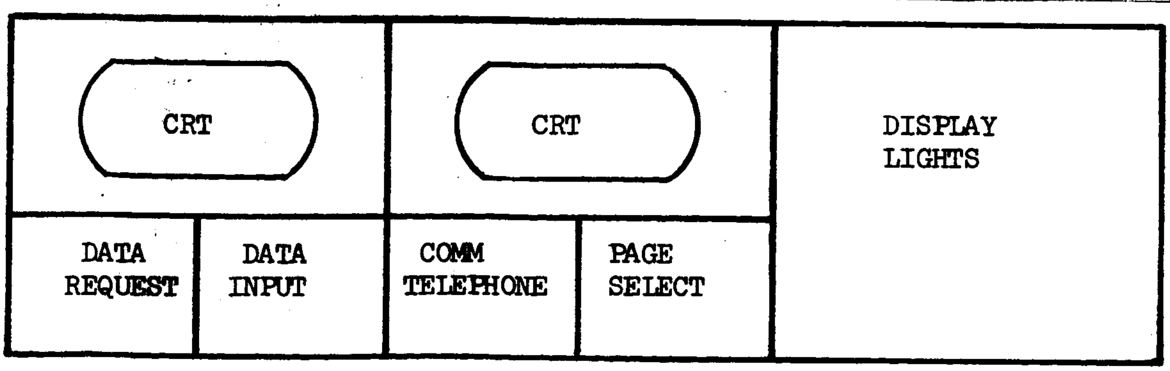


Table 6.4.4.9-5

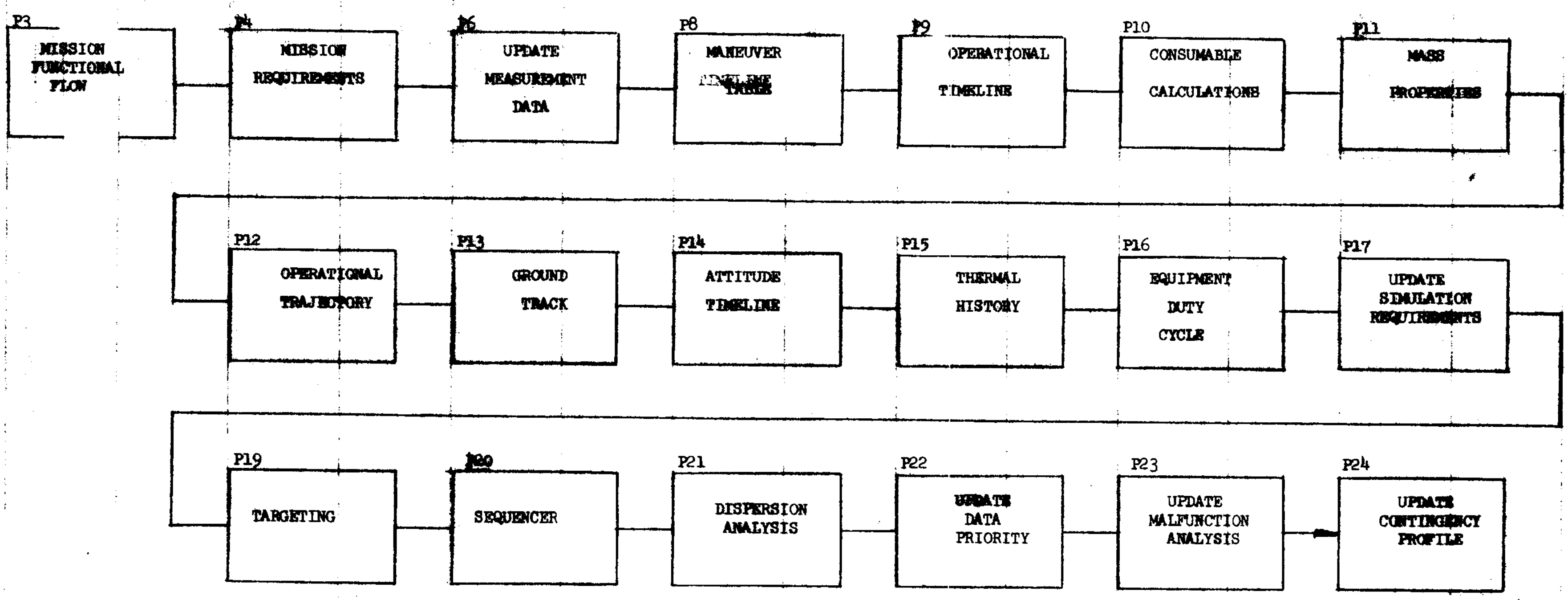
Mission Control Center Cost Estimate

Real Time Computer and Peripherials	3 @ .7	2.10M
Time Code Generator System		.05M
Peripherial Switch		.05M
Real Time Mission Planner Console	2@ .065	.13M
Operations Mgr Console	2@ .015	.03
Payload Interface Console	2@ .04	.08
Systems Monitor Console	2@ .04	.08
Rendezvous Docking & Servicing Console	2@ .04	.08
Modems	GFE	GFE
Analogue Recorders	2@ .03	.06
Simulator Interface Computer	1@ .06	.06
Rendezvous Docking & Serv. Display	1@ .27	.27
Mission Para. Computer, Etc.	GFE	GFE
Common Data Base, etc.	GFE	GFE
System Cables	150@ $400.	.06
with docking & servicing display		$3.05M
w/o docking & servicing display		2.78M

Facilities East Coast .412 M
Facilities West Coast .494 M

FLIGHT OPERATIONS WBS 320-11 (NASA) and 320-12 (DOD) RECURRING

FLIGHT PLANNING WBS 320-11-01 (NASA) 320-12-01 (DOD)



NASA ▲
DOD △

TABLE 6.4.4.10-2 TYPICAL MISSION ACTIVITIES - 1982

FLT. NO.

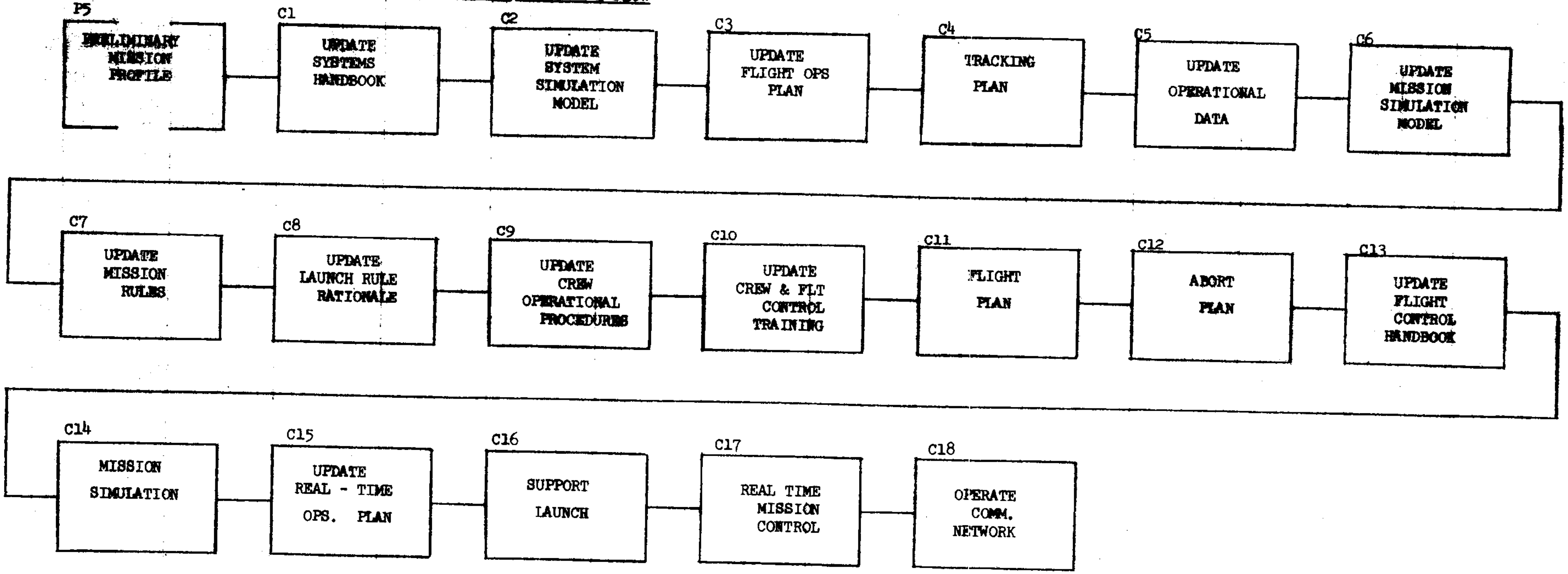
	25 ▲	26 △	27 ▲	28 △	29 ▲	30 △	31 ▲	32 △	33 ▲	34 △
	JULY		AUG.	SEPT.	OCT.		NOV.	DEC.	JAN.	

TASK	
FLIGHT PLANNING	
P4 Mission Requirements	1
P8 Maneuver Table	3
P7 Auto Mission Design	4
P17 Update Simulation Req'mts	1
P19 Targeting	$1\frac{1}{2}$
P20 Sequencer	$1\frac{1}{2}$
P21 Dispersion Analysis	2
P22 Data Priority	2
	TOTAL 16
FLIGHT CONTROL	
C-1 Update Systems Handbook	2
C-2 Update Sys. Sim. Model	$\frac{1}{2}$
C-5 Update Operational Data	2
C-6 Update Mission Sim. Model	$\frac{1}{2}$
C-7 Update Mission Rules	1
C-9 Update Crew Ops. Procedures	1
C-10 Update Crew & Flt.Ops.Train.	2
C-11 Flight Plan	2
C-13 Update Flt. Cont. Handbook	1
C-14 Mission Simulation	24 (4 Shifts)
C-16 Support Launch	
C-17 Real Time Mission Control	
C-18 Operate Comm. Network	
	TOTAL 36
FLIGHT EVALUATION	
E-3 Post Flt. Eval	1
E-4 Problem Resolution	1
	TOTAL 2
	54
SOFTWARE	
S-1 Update Onb'd. Sys. Programs	Costed in Software Word Estimate
S-2 Update Auto Miss. Design	
S-3 Update Sys. Sim. Programs	
S-4 Update Miss. Sim Programs	
S-5 Update Orbiter Control Prog.	
S-8 Update Real Time Prediction	

CHART 6.4.4.11-1

FLIGHT OPERATIONS WBS 320-11 (NASA) AND 320-12 (DOD) RECURRING

FLIGHT CONTROL WBS 320-11-02 NASA 320-12-02 (DOD) FUNCTIONAL FLOW



NASA ▲
DOD △

TABLE 6.4.4.11-2 TYPICAL MISSION ACTIVITIES - 1982

FLT. NO.: 25 ▲, 26 △, 27 ▲, 28 △, 29 ▲, 30 △, 31 ▲, 32 △, 33 ▲, 34 △

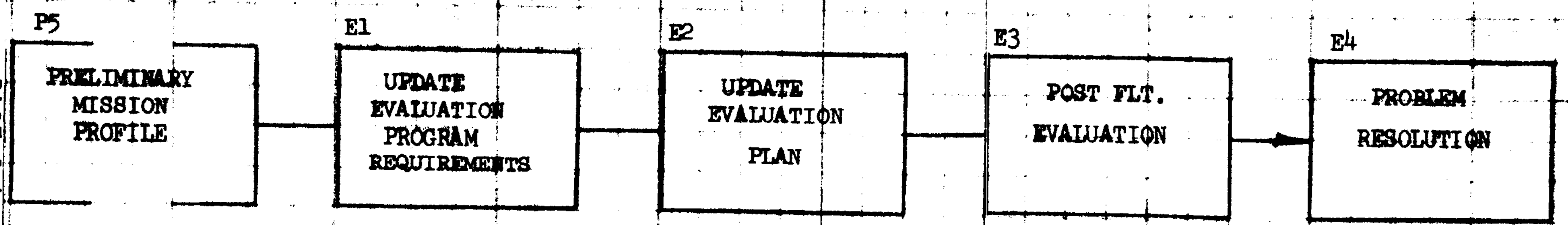
JULY, AUG., SEPT., OCT., NOV., DEC., JAN.

TASK	
FLIGHT PLANNING	
P4 Mission Requirements	1
P8 Maneuver Table	3
P7 Auto Mission Design	4
P17 Update Simulation Req'mts	1
P19 Targeting	$1\frac{1}{2}$
P20 Sequencer	$1\frac{1}{2}$
P21 Dispersion Analysis	2
P22 Data Priority	2
	TOTAL 16
FLIGHT CONTROL	
C-1 Update Systems Handbook	2
C-2 Update Sys. Sim. Model	$\frac{1}{2}$
C-5 Update Operational Data	2
C-6 Update Mission Sim. Model	$\frac{1}{2}$
C-7 Update Mission Rules	1
C-9 Update Crew Ops. Procedures	1
C-10 Update Crew & Flt.Ops.Train.	2
C-11 Flight Plan	2
C-13 Update Flt. Cont. Handbook	1
C-14 Mission Simulation	24 (4 Shifts)
C-16 Support Launch	
C-17 Real Time Mission Control	
C-18 Operate Comm. Network	
	TOTAL 36
FLIGHT EVALUATION	
E-3 Post Flt. Eval	1
E-4 Problem Resolution	1
	TOTAL 2
	54
SOFTWARE	
S-1 Update Onb'd. Sys. Programs	Costed in Software Word Estimate
S-2 Update Auto Miss. Design	
S-3 Update Sys. Sim. Programs	
S-4 Update Miss. Sim Programs	
S-5 Update Orbiter Control Prog.	
S-8 Update Real Time Prediction	

CHART 6.4.4.12-1

FLIGHT OPERATIONS WBS 320-11 (NASA) & -12 (DOD) RECURRING

FLIGHT EVALUATION WBS 320-11-03 (NASA) 320-12-03 (DOD)



NASA ▲

DOD △

TABLE 6.4.4.12-2 **TYPICAL MISSION ACTIVITIES - 1982**

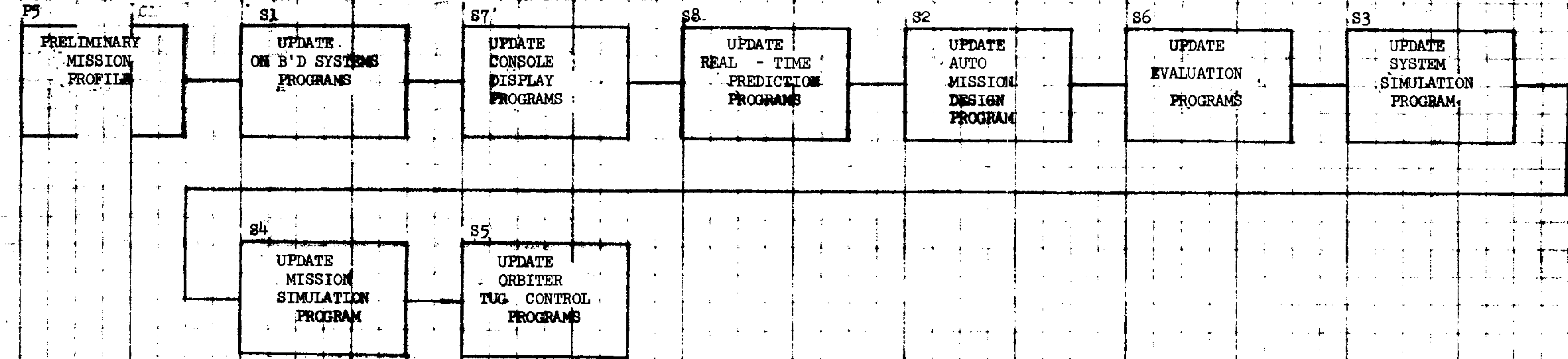
FLT. NO.	25 ▲	26 △	27 ▲	28 △	29 ▲	30 △	31 ▲	32 △	33 ▲	34 △

Months: JULY, AUG., SEPT., OCT., NOV., DEC., JAN.

TASK	
FLIGHT PLANNING	
P4 Mission Requirements	1
P8 Maneuver Table	3
P7 Auto Mission Design	4
P17 Update Simulation Req'mts	1
P19 Targeting	1½
P20 Sequencer	1½
P21 Dispersion Analysis	2
P22 Data Priority	2
	TOTAL 16
FLIGHT CONTROL	
C-1 Update Systems Handbook	2
C-2 Update Sys. Sim. Model	½
C-5 Update Operational Data	2
C-6 Update Mission Sim. Model	½
C-7 Update Mission Rules	1
C-9 Update Crew Ops. Procedures	1
C-10 Update Crew & Flt.Ops.Train.	2
C-11 Flight Plan	2
C-13 Update Flt. Cont. Handbook	1
C-14 Mission Simulation	24 (4 Shifts), covering C-14 to C-18
C-16 Support Launch	
C-17 Real Time Mission Control	
C-18 Operate Comm. Network	
	TOTAL 36
FLIGHT EVALUATION	
E-3 Post Flt. Eval	1
E-4 Problem Resolution	1
	TOTAL 2
	54
SOFTWARE	
S-1 Update Onb'd. Sys. Programs	Costed in Software Word Estimate, covering S-1 to S-8
S-2 Update Auto Miss. Design	
S-3 Update Sys. Sim. Programs	
S-4 Update Miss. Sim Programs	
S-5 Update Orbiter Control Prog.	
S-8 Update Real Time Prediction	

FLIGHT OPERATIONS WBS 320-11 (NASA) & -12 (DOD) RECURRING

SOFTWARE WBS 320-11-04 (NASA) 320-12-04 (DOD) FUNCTIONAL FLOW



NASA ▲
DOD △

TABLE 6.4.4.13-2

TYPICAL MISSION ACTIVITIES - 1982

FLT. NO.

TASK	25 ▲	26 △	27 ▲	28 △	29 ▲	30 △	31 ▲	32 △	33 ▲	34 △	
	JULY		AUG.	SEPT.	OCT.		NOV.	DEC.	JAN.		

FLIGHT PLANNING		
P4	Mission Requirements	1
P8	Maneuver Table	3
P7	Auto Mission Design	4
P17	Update Simulation Req'mts	1
P19	Targeting	$1\frac{1}{2}$
P20	Sequencer	$1\frac{1}{2}$
P21	Dispersion Analysis	2
P22	Data Priority	2
		TOTAL 16
FLIGHT CONTROL		
C-1	Update Systems Handbook	2
C-2	Update Sys. Sim. Model	$\frac{1}{2}$
C-5	Update Operational Data	2
C-6	Update Mission Sim. Model	$\frac{1}{2}$
C-7	Update Mission Rules	1
C-9	Update Crew Ops. Procedures	1
C-10	Update Crew & Flt.Ops.Train.	2
C-11	Flight Plan	2
C-13	Update Flt. Cont. Handbook	1
C-14	Mission Simulation	
C-16	Support Launch	24 (4 Shifts)
C-17	Real Time Mission Control	
C-18	Operate Comm. Network	
		TOTAL 36
FLIGHT EVALUATION		
E-3	Post Flt. Eval	1
E-4	Problem Resolution	1
		TOTAL 2
		54
SOFTWARE		
S-1	Update Onb'd. Sys. Programs	Costed in Software Word Estimate
S-2	Update Auto Miss. Design	
S-3	Update Sys. Sim. Programs	
S-4	Update Miss. Sim Programs	
S-5	Update Orbiter Control Prog.	
S-8	Update Real Time Prediction	

FLIGHT OPERATIONS CONTROL WBS 320-07-04 (NASA) 320-07-05 (DOD)

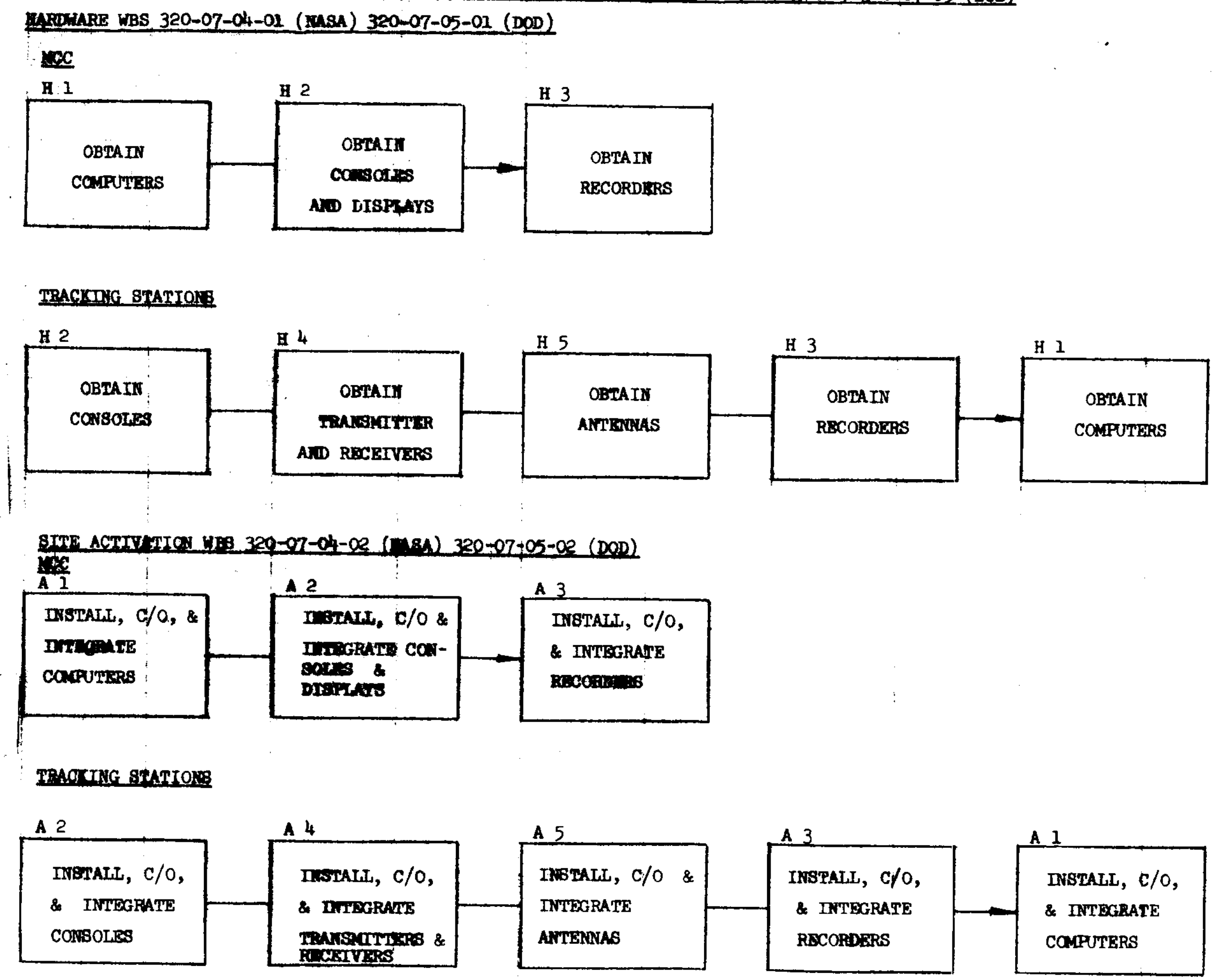


CHART 6.4.4.14-1

6.4.4.15 BASELINE COSTS

Table 6.4.4.15-1 is constructed as follows: Contractor man-year requirements are taken from Table 6.4.4-a; and NASA or DOD man-year requirements are assumed to be 50% of the contractor requirements (as stated in the assumptions list in Section 6.4.4). The computer time requirements are set as a function of mission flight time. The flight software DDT&E kiloword requirements, on-board and MCC, are taken from Table 6.2.5-7. VMMPS and SIM kiloword estimates are set based on previous flight program experience. Flight software for recurring operations per flight (NASA or DOD) were set as follows: with reference to Table 6.2.5-7, on-board and Ground (MCC) kilowords/flight = 0.1 S/S Monitor kilowords plus 0.25 x Sequencing kilowords.

With Table 6.4.4.15-1 established, a translation is made to Level 2 costs in Table 6.4.4.15-2. This is achieved in the following manner:

(1) Flight software cost estimates are established first, using the same technique used for autonomy Level 3 and making VMMPS proportional to ONBOARD and SIM proportional to MMC.

(2) Mission Planning requirements are made proportional to Flight Software ONBOARD requirements.

(3) Flight Control requirements are made proportional to Flight Software MCC requirements, and

(4) Flight Evaluation requirements are unchanged.

With the cost data factors in terms of man-year computer hours and kilowords now at hand for the 1-stage round-trip at 3 flights/year and at both autonomy Levels 3 and 2, translation is made to Tables 6.4.4.15-3 and 6.4.4.15-4 which are completely in terms of $M, by using the following procedure. Manyears are multiplied by 1860 MH/yr x 11.66 $/MH; computer hours are multiplied by 450 $/hr; and software kilowords are multiplied by 200,000 $/kiloword for non-recurring operations and 40,000 $/kiloword for recurring operations. Tables 6.4.4.15-5 and 6.4.4.15-6 represent a reduction; and Tables 6.4.4.15-7 and 6.4.4.15-8 represent final reduction to the reference or baseline costs for the 1 stage round-trip mission at autonomy Levels 3 and 2. Further expansion of data from these baseline costs to other flight-type missions is described in Section 6.4.4.16.

TABLE 6.4.4.15-1

COST DATA FACTORS: 1 STAGE, ROUND TRIP, AUTONOMY LEVEL 3

ITEM		DDT&E (NON-RECURRING)				FLIGHT TEST OPERATIONS (NON-RECURRING)				OPERATIONS PER FLIGHT (RECURRING)			
		NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R
MISSION PLANNING	MANPOWER (MY)	116/37	160/108	49/0	56/76	14/2	26/4	-	-	5	-	5	-
	SOFTWARE (KWDS)	0	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME (HRS)	-	-	-	-	-	-	-	-	6	-	6	-
FLIGHT CONTROL	MANPOWER (MY)	23/7	40/27	10/0	22/30	4/1	9/1	-	-	10	-	10	-
	SOFTWARE (KWDS)	0	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME (HRS)	-	-	-	-	-	-	-	-	200	-	200	-
FLIGHT EVALUATION	MANPOWER (MY)	7/2	10/7	10/0	8/11	4/0	8/1	-	-	1	-	1	-
	SOFTWARE (KWDS)	0	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME (HRS)	-	-	-	-	-	-	-	-	2	-	2	-
FLIGHT SOFTWARE	ONBOARD (KWDS)	22.41/8.80	-	-	-	-	-	-	-	0.715	-	0.715	-
	MCC (KWDS)	19.67/7.73	-	-	-	-	-	-	-	1.96	-	1.96	-
	TAMPS (KWDS)	21.54/8.46	-	-	-	-	-	-	-	-	-	-	-
	SPM (KWDS)	32.31/12.69	-	-	-	-	-	-	-	-	-	-	-

NOTES: (1) ---/--- Indicates (Before IOC/After IOC).

(2) Operations per flight based on 3 FLTS/YR.

(3) Flowcharting and programming for mission planning, flight control, and flight evaluation is included in manpower.

(4) Flight software DDT&E ratio of (Before IOC/After IOC) is proportional to (Deploy Complexity/Round Trip Complexity - Deploy Complexity)

TABLE 6.4.4.15-2

COST DATA FACTORS: 1 STAGE, ROUND TRIP, AUTONOMY LEVEL 2

ITEM			DDT&E (NON-RECURRING)				FLIGHT TEST OPERATIONS (NON-RECURRING)				OPERATIONS PER FLIGHT (RECURRING)			
			NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R
MISSION PLANNING	MANPOWER	(MY)	142/45	[illegible]/132	60/0	69/93	17/2	32/5	-	-	6	-	6	-
	SOFTWARE	(KWDS)	-	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME	(HRS)	-	-	-	-	-	-	-	-	7.35	-	7.35	-
FLIGHT CONTROL	MANPOWER	(MY)	10/3	[illegible]/11	4/0	9/13	2/0	4/0	-	-	5	-	[illegible]	-
	SOFTWARE	(KWDS)	-	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME	(HRS)	-	-	-	-	-	-	-	-	84.67	-	84.67	-
FLIGHT EVALUATION	MANPOWER	(MY)	7/2	[illegible]/7	[illegible]/0	8/11	4/0	8/1	-	-	1	-	1	-
	SOFTWARE	(KWDS)	-	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME	(HRS)	-	-	-	-	-	-	-	-	2	-	2	-
FLIGHT SOFTWARE	ONBOARD	(KWDS)	27.43/10.78	-	-	-	-	-	-	-	1.575	-	1.575	-
	MCC	(KWDS)	8.33/3.27	-	-	-	-	-	-	-	1.40	-	1.40	-
	[illegible]	(KWDS)	26.37/10.36	-	-	-	-	-	-	-	-	-	-	-
	SIM	(KWDS)	39.56/15.54	-	-	-	-	-	-	-	-	-	-	-

NOTES: (1) ---/--- Indicates (Before IOC/After IOC).

(2) Operations per flight based on 3 FLTS/YR.

(3) Flowcharting and programming for mission planning, flight control, and flight evaluation is included in manpower.

(4) Flight software DDT&E ratio of (Before IOC/After IOC) is proportional to (Deploy Complexity/Round Trip Complexity - Deploy Complexity)

TABLE 6.4.M.15-3

COST DATA: 1 STAGE, ROUND TRIP, AUTONOMY LEVEL 3, 3 FLTS/YR

$ M

ITEM		DDT&E (NON-RECURRING)				FLIGHT TEST OPERATIONS (NON-RECURRING)				OPERATIONS PER FLIGHT (RECURRING)			
		NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R
MISSION PLANNING	MANPOWER	2.52/0.80	3.47/2.34	1.06/0	1.21/1.65	0.30/.043	0.56/0.087	-	-	0.11	-	0.11	-
	SOFTWARE	-	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME	-	-	-	-	-	-	-	-	0.0027	-	0.0027	-
FLIGHT CONTROL	MANPOWER	0.50/0.15	0.87/0.59	0.22/0	0.48/0.65	0.087/0.022	0.20/0.022	-	-	0.26	-	0.26	-
	SOFTWARE	-	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME	-	-	-	-	-	-	-	-	0.09	-	0.09	-
FLIGHT EVALUATION	MANPOWER	0.15/0.043	0.22/0.15	0.22/0	0.17/0.24	0.087/0	0.17/.022	-	-	0.022	-	0.022	-
	SOFTWARE	-	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME	-	-	-	-	-	-	-	-	0.00090	-	0.00090	-
FLIGHT SOFTWARE	ONBOARD	4.48/1.76	-	-	-	-	-	-	-	0.029	-	0.029	-
	MCC	3.93/1.55	-	-	-	-	-	-	-	0.078	-	0.078	-
	VMOPS	4.31/1.69	-	-	-	-	-	-	-	-	-	-	-
	SIM	6.46/2.54	-	-	-	-	-	-	-	-	-	-	-

TABLE 6.4.4.15-4

COST DATA: 1 STAGE, ROUND TRIP, AUTONOMY LEVEL 2, 3 FLTS/YR.

$ M

ITEM		DDT&E (NON-RECURRING)				FLIGHT TEST OPERATIONS (NON-RECURRING)				OPERATIONS PER FLIGHT (RECURRING)			
		NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R
MISSION PLANNING	MANPOWER	3.08/0.98	4.25/2.86	1.30/0	1.50/2.02	0.37/0.043	0.69/0.11	-	-	0.13	-	0.13	-
	SOFTWARE	-	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME	-	-	-	-	-	-	-	-	0.0033	-	0.0033	-
FLIGHT CONTROL	MANPOWER	0.22/0.065	0.17/0.24	0.0[illegible]7/0	0.20/0.28	0.043/0	0.0[illegible]7/0	-	-	0.11	-	0.11	-
	SOFTWARE	-	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME	-	-	-	-	-	-	-	-	0.038	-	0.038	-
FLIGHT EVALUATION	MANPOWER	0.15/0.043	0.22/0.15	0.22/0	0.17/0.24	0.0[illegible]7/0	0.17/0.022	-	-	0.022	-	0.022	-
	SOFTWARE	-	-	-	-	-	-	-	-	-	-	-	-
	COMPUTER TIME	-	-	-	-	-	-	-	-	0.00090	-	0.00090	-
FLIGHT SOFTWARE	ONBOARD	5.49/2.16	-	-	-	-	-	-	-	0.063	-	0.063	-
	MCC	1.67/0.65	-	-	-	-	-	-	-	0.056	-	0.056	-
	[illegible]	5.[illegible]/2.[illegible]	-	-	-	-	-	-	-	—	-	—	-
	SIM	7.91/3.11	-	-	-	-	-	-	-	-	-	-	-

TABLE 6.4.4.15-5

COST DATA: 1 STAGE, ROUND TRIP, AUTONOMY LEVEL 3, 3 FLTS/YR.

	$M											
	DDT&E (NON-RECURRING)				FLIGHT TEST OPERATIONS (NON-RECURRING)				OPERATIONS PER FLIGHT (RECURRING)			
	NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R
MISSION PLANNING	2.52/0.80	3.47/2.34	1.06/0	1.21/1.65	0.30/0.043	0.56/0.087	-	-	0.11	-	0.11	-
FLIGHT CONTROL	0.50/0.15	0.87/0.59	0.22/0	0.48/0.65	0.087/0.022	0.20/0.022	-	-	0.35	-	0.35	-
FLIGHT EVALUATION	0.15/0.043	0.22/0.15	0.22/0	0.17/0.24	0.087/0	0.17/0.022	-	-	0.023	-	0.023	-
FLIGHT SOFTWARE	19.18/7.54	-	-	-	-	-	-	-	0.11	-	0.11	-
TOTALS	22.35/8.53	4.56/3.08	1.50/0	1.86/2.54	0.47/0.065	0.93/1.06	-	-	0.59	-	0.59	-
TOTALS	26.91/11.61		3.36/2.54		1.40/1.13		-		TOTAL COST/FLIGHT → NASA 0.59		TOTAL COST/FLIGHT → DOD 0.59	

TOTAL NON-RECURRING NASA 28.31/12.74

TOTAL NON-RECURRING DOD 3.36/2.54

TABLE 6.-.4.15-6

COST DATA: 1 STAGE, ROUND TRIP, AUTONOMY LEVEL 2, 3 FLTS/YR.

	$M											
	DDT&E (NON-RECURRING)				FLIGHT TEST OPERATIONS (NON-RECURRING)				OPERATIONS PER FLIGHT (RECURRING)			
	NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R	NASA	NASA CONTR'R	DOD	DOD CONTR'R
MISSION PLANNING	3.08/0.98	4.25/2.86	1.30/0	1.50/2.02	0.37/0.043	0.69/0.11	-	-	0.13	-	0.13	-
FLIGHT CONTROL	0.22/0.065	0.37/0.24	0.087/0	0.20/0.28	0.043/0	0.087/0	-	-	0.15	-	0.15	-
FLIGHT EVALUATION	0.15/0.043	0.22/0.15	0.22/0	0.17/0.24	0.087/0	0.17/0.022	-	-	0.023	-	0.023	-
FLIGHT SOFTWARE	20.34/7.99	-	-	-	-	-	-	-	0.12	-	0.12	-
TOTALS	23.79/9.08	4.84/3.25	1.61/0	1.87/4.41	0.5/0.043	0.95/0.13	-	-	0.42	-	0.42	-
TOTALS	28.63/12.33		3.48/4.41		1.45/0.17		-		TOTAL COST/FLIGHT NASA	0.42	TOTAL COST/FLIGHT DOD	0.42

TOTAL NON-RECURRING NASA 30.08/12.50

TOTAL NON-RECURRING DOD 3.48/4.41

TABLE 6.4.4.15-7 COST DATA: 1 STAGE, ROUND TRIP, AUTONOMY LEVEL 3, 3 FLTS/YR.

		NON- RECURRING, $ M			RECURRING, $ M
		DDT&E	FLT TEST OPS	TOTAL NON-RECURRING	OPS PER FLT
NASA	MISSION PLAN	5.99/3.14	0.86/0.13	6.85/3.27	0.11
	FLT CONTROL	1.37/0.74	0.29/0.04	1.66/0.78	0.35
	FLT EVAL.	0.37/0.19	0.26/0.022	0.63/0.21	0.023
	FLT SOFTWARE	19.18/7.54	--	19.18/7.54	0.11
	TOTALS	26.91/11.61	1.41/0.19	28.32/11.80	0.59
DOD	MISSION PLAN	2.27/1.65	--	2.27/1.65	0.11
	FLT CONTROL	0.70/0.65	--	0.70/0.65	0.35
	FLT EVAL.	0.39/0.24	--	0.39/0.24	0.023
	FLT SOFTWARE	--	--	--	0.11
	TOTALS	3.36/2.54	--	3.36/2.54	0.59

TABLE 6.4.4.15-8 COST DATA: 1 STAGE, ROUND TRIP, AUTONOMY LEVEL 2, 3 FLTS/YR.

		NON-RECURRING, $M			RECURRING, $M
		DDT&E	FLT TEST OPS	TOTAL NON-RECURRING	OPS PER FLT
NASA	MISSION PLAN	7.33/3.84	1.06/0.15	8.39/3.99	0.13
	FLT CONTROL	0.59/0.31	0.13/0	0.72/0.31	0.15
	FLT EVAL.	0.37/0.19	0.26/0.022	0.63/0.21	0.023
	FLT SOFTWARE	20.34/7.99	--	20.34/7.99	0.12
	TOTALS	28.63/12.33	1.45/0.17	30.08/12.50	0.42
DOD	MISSION PLAN	2.80/2.02	--	2.80/2.02	0.13
	FLT CONTROL	0.29/0.28	--	0.29/0.28	0.15
	FLT EVAL.	0.39/0.24	--	0.39/0.24	0.023
	FLT SOFTWARE	--	--	--	0.12
	TOTALS	3.48/2.54	--	3.48/2.54	0.42

6.4.4.16 Application of Complexity Factors to Baseline Costs

Baseline costs are shown in Tables 6.4.4.15-7 and 6.4.4.15-8 for the 1 stage round trip mission using autonomy level 3 at a flight frequency of 3 flts/yr. The next step is to obtain costs for the other types of flights. This is done by multiplying the baseline costs shown in Tables 6.4.4.15-7 & 6.4.4.15-8 by the following ratio of complexity factors,

$$\boxed{\frac{\text{Complexity Factor for Selected Type of Flt}}{\text{Complexity Factor for Round Trip (117)}}}$$

, where the complexity factor for each type of flight is given in Table 6.2.5-1. The results of this step are the costs given in Tables 6.4.4.16-1 through 6.4.4.16-3. These are the tables which are applied to a particular configuration - option.

SYMBOLS

D	-	1 STAGE DEPLOYS PL
DK	-	1 STAGE DEPLOYS PL - AKS
DE	-	1 STAGE DEPLOYS PL. TUG IS EXPENDED
MD	-	1 STAGE MULTI-DEPLOYS (2 PL)
MDK	-	1 STAGE MULTI-DEPLOYS (2 PL - AKS)
R	-	1 STAGE RETRIEVES PL OR RETRIEVAL DELAYED PL OR PL-DKS
RT	-	1 STAGE DEPLOYS PL AND RETRIEVES PL
RTK	-	1 STAGE DEPLOYS PL - AKS AND RETRIEVES PL - DKS
DN	-	1 STAGE DEPLOYS PL AND RETRIEVAL DELAYS PL.
DKN	-	1 STAGE DEPLOYS PL - AKS AND RETRIEVAL DELAYS PL.
2D	-	2 STAGES DEPLOY PL, USING SLING - SHOT TECHNIQUE. 1ST STAGE DEPLOYS 2ND STAGE AND RETURNS. 2ND STAGE DEPLOYS PL AND RETURNS
2RT	-	2 STAGES DEPLOY PL AND RETRIEVE PL, USING REVERSE SLING-SHOT TECHNIQUE. 1ST STAGE DEPLOYS PL AND RETRIEVES PL AND ORBITS. 2ND STAGE RETRIEVES 1ST STAGE AND RETURNS.
SO	-	1 STAGE SORTIE: CARRIES PL TO MISSION ORBIT, REMAINS WITH PL THROUGHOUT MISSION, AND RETURNS WITH PL.
S	-	1 STAGE SERVICES 1 OR MORE PL (2 PL). TYPE 1: REPLACED PART DISCARDED. TYPE 2: REPLACED PART BROUGHT BACK

MDN	1 Stage Multi-Deploys (2 PL) and Retrieval Delays PL.
N	1 Stage Retrieval Delays PL.
MDR	1 Stage Multi-Deploys (2 PL) and Retrieves PL.
2DE	2 Tandem Stages Deploy 1 PL. Both Stages are Expended.
2MD	2 Stages Multi-Deploy PL, using Sling-Shot Technique. First Stage Deploys Second Stage and Returns. Second Stage Multi-Deploys (2 PL) and Returns.
2R	2 Stages Retrieve PL, using Reverse Sling-Shot Technique. First Stage Retrieves PL and Orbits. Second Stage Retrieves First Stage and Returns.
2MDR	2 Stages Multi-Deploy (2 PL) and Retrieve PL, using Reverse Sling-Shot Technique. First Stage Multi-Deploys 2 PL and Retrieves 1 PL and Orbits. Second Stage Retrieves First Stage and Returns.

TABLE 6.4.4.16-1

NON-RECURRING FLIGHT OPERATIONS COST, AUTONOMY LEVEL 3

			NON-RECURRING FLIGHT OPERATIONS COST, $M													
			D	DK	DE	MD	MDK	R	RT	RTK	DN	DKN	2D	MDN	2MD	2MDR
NASA	DDT&E	MISSION PLANNING	4.30/2.25	5.5[illegible]/2.90		5.22/2.74	7.68/4.03		5.99/3.14	8.75/4.59	6.66/3.49			7.58/3.97	7.88/4.13	9.42/4.94
		FLIGHT CONTROL	0.98/0.5[illegible]	1.26/0.68		1.19/0.65	1.76/0.95		1.37/0.74	2.00/1.08	1.52/0.82			1.73/0.94	1.80/0.97	2.15/1.16
		FLIGHT EVALUATION	0.27/0.14	0.34/0.18		0.32/0.17	0.47/0.24		0.37/0.19	0.54/0.28	0.41/0.21			0.47/0.24	0.49/0.25	0.58/0.30
		FLIGHT SOFTWARE	13.77/5.41	17.71/6.96		16.72/6.57	24.59/9.67		19.18/7.54	28.03/11.02	21.31/8.38			24.26/9.54	25.24/9.92	30.16/11.86
		TOTAL	19.3[illegible]/8.3[illegible]	24.84/10.72		23.45/10.13	34.50/14.89		26.91/11.61	39.32/16.97	29.90/12.90			34.04/14.69	35.41/15.27	42.31/18.26
	FLIGHT TEST OPERATIONS	MISSION PLANNING	0.62/0.09	0.79/0.12		0.75/0.11	1.10/0.17		0.86/0.13	1.26/0.19	0.96/0.14			1.09/0.16	1.13/0.17	1.35/0.20
		FLIGHT CONTROL	0.21/0.03	0.27/0.034		0.25/0.035	0.37/0.051		0.29/0.04	0.42/0.058	0.32/0.044			0.37/0.051	0.38/0.05	0.46/0.06
		FLIGHT EVALUATION	0.19/0.016	0.24/0.02		0.23/0.019	0.33/0.028		0.26/0.022	0.38/0.032	0.29/0.024			0.33/0.028	0.34/0.029	0.41/0.03
		FLIGHT SOFTWARE	0/0	0/0		0/0	0/0		0/0	0/0	0/0			0/0	0/0	0/0
		TOTAL	1.02/0.136	1.30/0.174		1.23/0.16	1.80/0.25		1.41/0.192	2.06/0.28	1.57/0.208			1.79/0.24	1.85/0.25	2.22/0.29
	TOTAL NON-RECURRING	MISSION PLANNING	4.92/2.35	6.32/3.02		5.97/2.85	8.79/4.19		6.85/3.27	10.01/4.78	7.61/3.63			8.67/4.14	9.02/4.30	10.77/5.14
		FLIGHT CONTROL	1.19/0.56	1.53/0.72		1.45/0.68	2.13/1.00		1.66/0.78	2.43/1.14	1.84/0.87			2.10/0.99	2.19/1.03	2.61/1.23
		FLIGHT EVALUATION	0.45/0.15	0.58/0.19		0.55/0.18	0.81/0.27		0.63/0.21	0.92/0.31	0.70/0.23			0.80/0.27	0.83/0.28	0.99/0.33
		FLIGHT SOFTWARE	13.77/5.41	17.71/6.96		16.72/6.57	24.59/9.67		19.18/7.54	28.03/11.02	21.31/8.38			24.26/9.54	25.24/9.92	30.16/11.86
		TOTAL														
DOD	DDT&E	MISSION PLANNING	1.63/2.69	2.10/1.52		1.98/1.44	2.91/2.12		2.27/1.65	3.32/2.41	2.53/1.83			2.87/2.09	2.99/2.17	3.48/2.59
		FLIGHT CONTROL	0.50/0.47	0.65/0.60		0.61/0.57	0.90/0.83		0.70/0.65	1.02/0.95	0.78/0.72			0.89/0.82	0.92/0.86	1.10/1.02
		FLIGHT EVALUATION	0.28/0.17	0.36/0.22		0.34/0.21	0.50/0.31		0.39/0.24	0.57/0.35	0.43/0.27			0.49/0.30	0.51/0.32	0.61/0.38
		FLIGHT SOFTWARE	0/0	0/0		0/0	0/0		0/0	0/0	0/0			0/0	0/0	0/0
		TOTAL														
	FLIGHT TEST OPERATIONS	MISSION PLANNING	0/0													
		FLIGHT CONTROL	0/0													
		FLIGHT EVALUATION	0/0													
		FLIGHT SOFTWARE	0/0													
		TOTAL	0/0													
	TOTAL NON-RECURRING	MISSION PLANNING														
		FLIGHT CONTROL														
		FLIGHT EVALUATION	SAME		AS	DDT&E										
		FLIGHT SOFTWARE														
		TOTAL														
NORMALIZED COMPLEXITY F			0.7179	0.9231	0.2735	0.8718	1.2821	0.7692	1.0000	1.4615	1.1111	1.2735	1.1111	1.2650	1.3162	1.5726

TABLE 6.4.4.16-3. RECURRING FLIGHT OPERATIONS COST, 3 FLTS/YR

			RECURRING FLT OPS COST $ M												
			D	DK	DE	MD	MDK	R	RT	RTK	DN	DKN	2D	2RT	SO
NASA	AUTONOMY LEVEL 3	MISSION PLAN	0.079	0.10	0.030	0.096	0.14	0.085	0.11	0.16	0.12	0.14	0.12	0.16	0.067
		FLT CONTROL	0.25	0.32	0.096	0.31	0.45	0.27	0.35	0.51	0.39	0.45	0.39	0.50	0.21
		FLT EVAL.	0.017	0.021	0.0063	0.020	0.029	0.018	0.023	0.034	0.026	0.029	0.026	0.033	0.014
		FLT SOFTWARE	0.079	0.10	0.030	0.096	0.14	0.085	0.11	0.16	0.12	0.14	0.12	0.16	0.067
		TOTAL	0.39	0.51	0.15	0.48	0.71	0.42	0.55	0.80	0.61	0.70	0.61	0.79	0.33
	AUTONOMY LEVEL 2	MISSION PLAN	0.093	0.12	0.036	0.11	0.17	0.10	0.13	0.19	0.14	0.17	0.14	0.19	0.079
		FLT CONTROL	0.11	0.14	0.041	0.13	0.19	0.12	0.15	0.22	0.17	0.19	0.17	0.22	0.091
		FLT EVAL.	0.017	0.021	0.0063	0.020	0.029	0.018	0.023	0.034	0.026	0.029	0.026	0.033	0.014
		FLT SOFTWARE	0.086	0.11	0.033	0.10	0.15	0.092	0.12	0.18	0.13	0.15	0.13	0.17	0.073
		TOTAL	0.29	0.37	0.11	0.35	0.51	0.31	0.40	0.58	0.44	0.51	0.44	0.57	0.24
DOD	AUTONOMY LEVEL 3	MISSION PLAN	0.079	0.10	0.030	0.096	0.14	0.085	0.11	0.16	0.12	0.14	0.12	0.16	0.067
		FLT CONTROL	0.25	0.32	0.096	0.31	0.45	0.27	0.35	0.51	0.39	0.45	0.39	0.50	0.21
		FLT EVAL.	0.017	0.021	0.0063	0.020	0.029	0.018	0.023	0.034	0.026	0.029	0.026	0.033	0.014
		FLT SOFTWARE	0.079	0.10	0.03	0.096	0.14	0.085	0.11	0.16	0.12	0.14	0.12	0.16	0.067
		TOTAL	0.39	0.51	0.15	0.48	0.71	0.42	0.55	0.80	0.61	0.70	0.61	0.79	0.33
	AUTONOMY LEVEL 2	MISSION PLAN	0.093	0.12	0.036	0.11	0.17	0.10	0.13	0.19	0.14	0.17	0.14	0.19	0.079
		FLT CONTROL	0.11	0.14	0.041	0.13	0.19	0.12	0.15	0.22	0.17	0.19	0.17	0.22	0.091
		FLT EVAL	0.017	0.021	0.0063	0.020	0.029	0.018	0.023	0.034	0.026	0.029	0.026	0.033	0.014
		FLT SOFTWARE	0.086	0.11	0.033	0.10	0.15	0.092	0.12	0.18	0.13	0.15	0.13	0.17	0.073
		TOTAL	0.29	0.37	0.11	0.35	0.51	0.31	0.40	0.58	0.44	0.51	0.44	0.57	0.24
NORMALIZED COMPLEXITY FACTOR:			0.7179	0.9231	0.2735	0.8718	1.2821	0.7692	1.0000	1.4615	1.1111	1.2735	1.1111	1.4359	0.6068

TABLE 6.4.4.16 RECURRING FLIGHT OPERATIONS COST, 3 FLTS/YR (CONTINUATION)

			RECURRING FLT OPS COST $ M			
			MDN	N	MDR	S (2 PL)
NASA	AUTONOMY LEVEL 3	MISSION PLAN	.14	.083	.13	.16
		FLT CONTROL	.44	.26	.42	.50
		FLT EVAL.	.029	.017	.027	.033
		FLT SOFTWARE	.14	.083	.13	.16
		TOTAL				
	AUTONOMY LEVEL 2	MISSION PLAN	.16	.098	.15	.19
		FLT CONTROL	.19	.11	.18	.22
		FLT EVAL.	.029	.017	.027	.033
		FLT SOFTWARE	.15	.090	.14	.17
		TOTAL				
DOD	AUTONOMY LEVEL 3	MISSION PLAN	.14	.083	.13	.16
		FLT CONTROL	.44	.26	.42	.50
		FLT EVAL.	.029	.017	.027	.033
		FLT SOFTWARE	.14	.083	.13	.16
		TOTAL				
	AUTONOMY LEVEL 2	MISSION PLAN	.16	.098	.15	.19
		FLT CONTROL	.19	.11	.18	.22
		FLT EVAL.	.029	.017	.027	.033
		FLT SOFTWARE	.15	.090	.14	0.17
		TOTAL				
			1.2650	0.7521	1.1880	1.4359

6.4.4.17 Network Operations Costs

Remote Site Costs - DOD

The Remote Sites in the AFSCF network includes 3 Dual Tracking Stations and 4 Single Tracking Stations. Operationally, the Remote Station team is directed by the Operations Controller who operates a Station Operators Console where status and station configuration are displayed visually. The Operations Controller is in voice communication with the appropriate Controller in the assigned Mission Control Complex at the STC. Each site is time shared by TUG, Payloads and Shuttle. Scheduling of Remote Site Time is directed from the STC. Costs are then shared on a time usage basis.

$ = # Men at Site x Flight Time x
Duty Factor x Rate

Additional costs should be charged for training each Controller team at:

$ = Men x Training Time x Rate

o Remote Site Costs - NASA

A similar approach utilized above to cost DOD will be used for NASA remote sites.

6.4.5 Cost Data Sheets

Tables 6.4.4.16-1 through 6.4.4.16-3 are used to obtain cost data for a selected configuration - option. A description of the procedure is given for a configuration which evolves, namely 310 → 310RE, Option 3A. The processing for the other programs which evolve is similar. In the case of the programs which do not evolve, the procedure is a reduced version.

Recurring Costs

Recurring costs are computed initially as shown in Table 6.4.5-1, separated into 2 parts: Level 3 (1980, 81, 82) and Level 2 (1983 through 1990). In this table, the number of flights in each flight-type category is taken from the capture analysis and the costs per flight for mission planning, flight control, flight evaluation, and flight software are taken from the reference cost tables (Tables 6.4.4.1 through 6.4.4.16-3). The costs per flight are then multiplied by the nos. of flights to get total costs.

The next step is to compute costs for the year 1983 at autonomy level 2, which is shown at the top of Table 6.4.5-2. In the lower half of Table 6.4.5-2, the 1983 autonomy Level 2 costs are added to the 1980, 81, 82 autonomy level 3 costs from Table 6.4.5-1 to get the recurring costs for the initial configuration. Similarly, the 1983 autonomy level 2 costs are subtracted from the 1983 through 1990 antonomy level 2 costs from Table 6.4.5-1. The results are brought to Table 6.4.5-3, where adjustments are made to account for the number of flights per year being different than the baseline level of 3 per year. The recurring manpower requirements per flight (mission planning, flight control, + flight evaluation) as a function of the no. of flts/yr. are shown in Fig. 6.4.5-1.

Nonrecurring Costs

With regard to nonrecurring costs, the appropriate data from Reference Tables 6.4.4 through 6.4.4.16-3 are inserted into Table 6.4.5-4. For the initial configuration Mission Planning DDT&E, the first row of numbers, 6.39/3.35 represent costs for the highest complexity factor type of flight flown in the autonomy level 2 year 1983, in this case, a multi-deploy. The next row of cost numbers, 5.22/2.74 is for the highest complexity - factor type of flight flown in the antonomy level 3 years 1980, 81 and 82. The next row is obtained by taking for pre-IOC, the level 3 no. 5.22 and for post-IOC, the post-IOC level 2 no. 3.35 plus the difference between the pre-IOC nos. 6.39 and 5.22. The same procedure is used for the other categories under initial configuration DDT&E or Flt. Test, with the one exception being in flight control where both level 3 nos. (2nd row) are taken for the 3rd row.

In the case of the evolved configuration mission planning DDT&E, the top row 9.27/4.86 is for the highest complexity factor type of flight flown in the years 1984 through 1990. The 2nd row 6.39/3.35 is the same as the first row under initial configuration mission planning DDT&E, i.e., level 2 1983. The 3rd row 2.88/1.51 is the difference between the 1st and 2nd rows. The other sets are done in the same way for the evolved configuration DDT&E or flight test.

Using the procedures described above, costs were obtained for the 6 programs and are summarized in Tables 6.4.5.1-1 through 6.4.5.4-4.

TABLE 6.4.5-1

CONFIGURATION 310 - 3A ⟶ 310 RE - 3A IOC Dec '79/Dec '83

RECURRING FLT OPS COST $M

	TYPE OF FLT	NO FLTS	AUTONOMY LEVEL 3 COST/FLT MP	FC	FE	FS	TOT	AUTONOMY LEVEL 3 TOT COST MP	FC	FE	FS	TOT	NO FLTS	AUTONOMY LEVEL 2 COST/FLT MP	FC	FE	FS	TOT	AUTONOMY LEVEL 2 TOT COST MP	FC	FE	FS	TOT
NASA	D	6	0.079	0.25	0.017	0.079	0.39	0.47	1.50	0.10	0.47	2.34	22	.093	0.11	0.017	0.086	0.29	2.05	2.42	0.37	1.89	6.38
	MD	8	0.096	0.31	0.020	0.096	0.48	0.77	2.48	0.16	0.77	3.84	22	.11	0.13	0.020	0.10	0.35	2.42	2.86	0.44	2.20	7.70
	DE	2	0.030	0.096	0.0063	0.030	0.15	0.06	0.19	0.013	0.06	0.30	15	.036	0.041	0.0063	0.033	0.11	0.54	0.62	0.095	0.50	1.65
	N	0	-	-	-	-	-	-	-	-	-	-	3	.098	0.11	0.017	0.090	0.30	0.29	0.33	0.051	0.27	0.90
	DN	0	-	-	-	-	-	-	-	-	-	-	37	.14	0.17	0.026	0.13	0.44	5.18	6.29	0.96	4.81	16.28
	MDN	0	-	-	-	-	-	-	-	-	-	-	2	.16	0.19	0.029	0.15	0.51	0.32	0.38	0.058	0.30	1.02
	R	0	-	-	-	-	-	-	-	-	-	-	57	.10	0.12	0.018	0.092	0.31	5.70	6.84	1.03	5.24	17.67
	RT	0	-	-	-	-	-	-	-	-	-	-	22	.13	0.15	0.023	0.12	0.40	2.86	3.30	0.51	2.64	8.80
	MDRT	0	-	-	-	-	-	-	-	-	-	-	4	.15	0.18	0.027	0.14	0.48	0.60	0.72	0.11	0.56	1.92
	SO	0	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-
						(highest C.F. = MD for NASA Level 3)											(highest C.F. = MDN for NASA Level 2)							
	Totals AVE. COST/FLT	16						1.30	4.17	0.27	1.30	6.48	184						19.96	23.76	3.62	18.41	62.32
DOD	D	12	0.079	0.25	0.017	0.079	0.39	0.95	3.00	0.20	0.95	4.68	20	.093	0.11	0.017	0.086	0.29	1.86	2.20	.34	1.72	5.80
	MD	4	0.096	0.31	0.020	0.096	0.48	0.38	1.24	0.08	0.38	1.92	29	.11	0.13	0.020	0.10	0.35	3.19	3.77	0.58	2.9	10.15
	DE	0	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	0	0	0	0	0
	N	0	-	-	-	-	-	-	-	-	-	-	2	.098	0.11	0.017	0.090	0.30	0.20	0.22	0.034	.18	0.60
	DN	0	-	-	-	-	-	-	-	-	-	-	12	.14	0.17	0.026	0.13	0.44	1.68	2.04	.31	1.56	5.28
	MDN	0	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	0	0	0	0	0
	R	0	-	-	-	-	-	-	-	-	-	-	38	.10	0.12	0.018	0.092	0.31	3.8	4.56	.68	3.50	11.78
	RT	0	-	-	-	-	-	-	-	-	-	-	39	.13	0.15	0.023	0.12	0.40	5.07	5.85	0.90	4.68	15.60
	MDRT	0	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	0	0	0	0	0
	SO	0	-	-	-	-	-	-	-	-	-	-	4	.079	0.091	0.014	0.073	0.24	.32	0.36	.056	.29	0.96
						(highest C.F. = MD for DOD, Level 3)											(highest C.F. is DN for DOD, Level 2)							
	Totals AVE. COST/FLT	16						1.33	4.24	0.28	1.33	6.60	144						16.12	19.00	2.90	14.83	50.17

TABLE 6.4.5-2

LEVEL 2 1983

310-3A → 310RE-3A

	Type of Flt.	No. Flts	COST/FLT MP	FC	FE	FS	TOTAL COST MP	FC	FE	FS
NASA	D	3	.093	.11	.017	.086	.28	.33	.051	.26
	MD	9	.11	.13	.02	0.1	.99	1.17	.18	.90
						TOTALS	1.27	1.50	.23	1.16
DOD	D	6	.093	.11	.017	.086	.56	.66	.10	.52
	MD	8	.11	.13	.02	.10	.88	1.04	.16	.80
	SO	1	.079	.091	.014	.073	.079	.091	.014	.073
						TOTALS	1.52	1.79	.27	1.39

	CONFIGURATION							
	Initial 310 - 3A				Evolved 310RE-3A			
	MP	FC	FE	FS	MP	FC	FE	FS
NASA Level 3	1.30	4.17	.27	1.30	19.96	23.76	3.62	18.41
Level 2,1983+	1.27 +	1.50 +	.23 +	1.16	- 1.27 _	1.50 -	.23 -	1.16
Total	2.57	5.67	0.50	2.46	18.69	25.26	3.39	17.25
DOD Level 3	1.33	4.24	.28	1.33	16.12	19.00	2.90	14.83
Level 2,1983+	1.52 +	1.79 +	.27 +	1.39	- 1.52 -	1.79 -	.27 -	1.39
Total	2.85	6.03	.55	2.72	14.6	20.79	2.63	13.44

	NO FLTS Initial Configuration	Evolved Configuration
NASA	28	172
DOD	31	129
NO. YRS	4	7

TABLE 6.4.5-3

CONFIGURATION 310-3A → 310RE-3A

IOC DEC '79/DEC '83

RECURRING FLT OPS COST, $M

		310-3A		310RE-3A	
N	MISSION PLANNING	(15/18)(2.57) = 2.13		(12/18)(18.69) = 12.33	
A	FLIGHT CONTROL	(9/35)(5.67)+(26/35)(15/18)(5.67)=3.45		(9/35)(25.26)+(26/35)(12/18)(25.26)=18.68	
S	FLIGHT EVALUATION	(15/18)(0.5) = .41		(12/18)(3.39)=2.23	
A	FLIGHT SOFTWARE	2.46		17.25	
	TOTALS		8.45		50.49
D	MISSION PLANNING	(15/18)(2.85)=2.36		(12/18)(14.6)=9.63	
O	FLIGHT CONTROL	(9/35)(6.03)+(26/35)(15/18)(6.03)=5.17		(9/35)(20.79)+(26/35)(12/18)(20.79)=15.37	
D	FLIGHT EVALUATION	(15/18)(0.55)=.45		(12/18)2.13 = 1.73	
	FLIGHT SOFTWARE	2.72		13.44	
	TOTALS		10.70		40.17

NOTES: (1) NASA 28 FLTS/4 YRS = 7 FLTS/YR AVERAGE → 15 MEN/FLT 310-3A

NASA 172 FLTS/7 YRS = 24.6 FLTS/YR AVERAGE → 12 MEN/FLT 310RE-3A

DOD 31 FLTS/4 YRS = 7.8 FLTS/YR AVERAGE → 15 MEN/FLT 310-3A

DOD 129 FLTS/7 YRS = 18.4 FLTS/YR AVERAGE → 12 MEN/FLT 310RE-3A

TABLE 6.4.5-4

CONFIGURATION 310-3A → 310RE-3A IOC DEC '79/DEC '83

NON-RECURRING FLT OPS COST, $M

		INITIAL CONFIGURATION 310-3A Autonomy Level 3: 1980,81,82 Autonomy Level 2: 1983					EVOLVED CONFIGURATION 310RE-3A (Autonomy Level 2)				
		DDT&E		FLT TESTS		TOTAL	DDT&E		FLT TESTS		TOTAL
	MISSION PLANNING	6.39	3.35	.92	.13		9.27	4.86	1.34	0.19	
N		5.22	2.74	.75	.11		6.39	3.35	0.92	0.13	
		5.22	4.52	.75	.30	5.97/4.82	2.88	1.51	0.42	0.06	3.30/ 1.57
A	FLIGHT CONTROL	0.51	0.27	.11	.016		0.75	0.39	0.16	0.023	
		1.19	0.65	.25	.035		0.51	0.27	0.11	0.016	
S		1.19	0.65	.25	.035	1.44/0.69	0.24	0.12	0.05	0.007	0.29/ 0.127
A	FLIGHT EVALUATION	.32	.17	.23	.019		0.47	0.24	0.33	0.028	
		0.32	.17	.23	.019		0.32	0.17	0.23	0.019	
		0.32	.17	.23	.019	0.55/0.189	0.15	0.07	0.10	0.009	0.25/ 0.079
	FLIGHT SOFTWARE	17.73	6.97	0	0		25.73	10.11	0	0	
		16.62	6.57	0	0		17.73	6.97	0	0	
		16.72	8.00	0	0	16.72/8.00	8.00	3.14	0	0	8.00/3.14
	TOTAL	23.45	13.34	1.23	0.354	24.68/13.70	11.27	4.84	0.57	0.076	11.84/4.92
	MISSION PLANNING	2.44	1.76	0	0		3.11	2.24	0	0	
D		1.98	1.44	0	0		2.44	1.76	0	0	
		1.98	2.22	0	0	1.98/2.22	0.67	0.48	0	0	0.67/0.48
O	FLIGHT CONTROL	.25	.24	0	0		0.32	0.31	0	0	
		.61	.57	0	0		0.25	0.24	0	0	
		0.61	.57	0	0	0.61/0.57	0.07	0.07	0	0	0.07/0.07
D	FLIGHT EVALUATION	.34	.21	0	0		0.43	0.27	0	0	
		.34	.21	0	0		0.34	0.21	0	0	
		0.34	.21	0	0	0.34/0.21	0.11	0.06	0	0	0.11/0.06
	FLIGHT SOFTWARE	0	0	0	0		0	0	0	0	
		0	0	0	0		0	0	0	0	
		0	0	0	0	0/0	0	0	0	0	0/0
	TOTAL	2.93	3.00	0	0	2.93/3.00	0.85	0.61	0	0	0.85/0.61

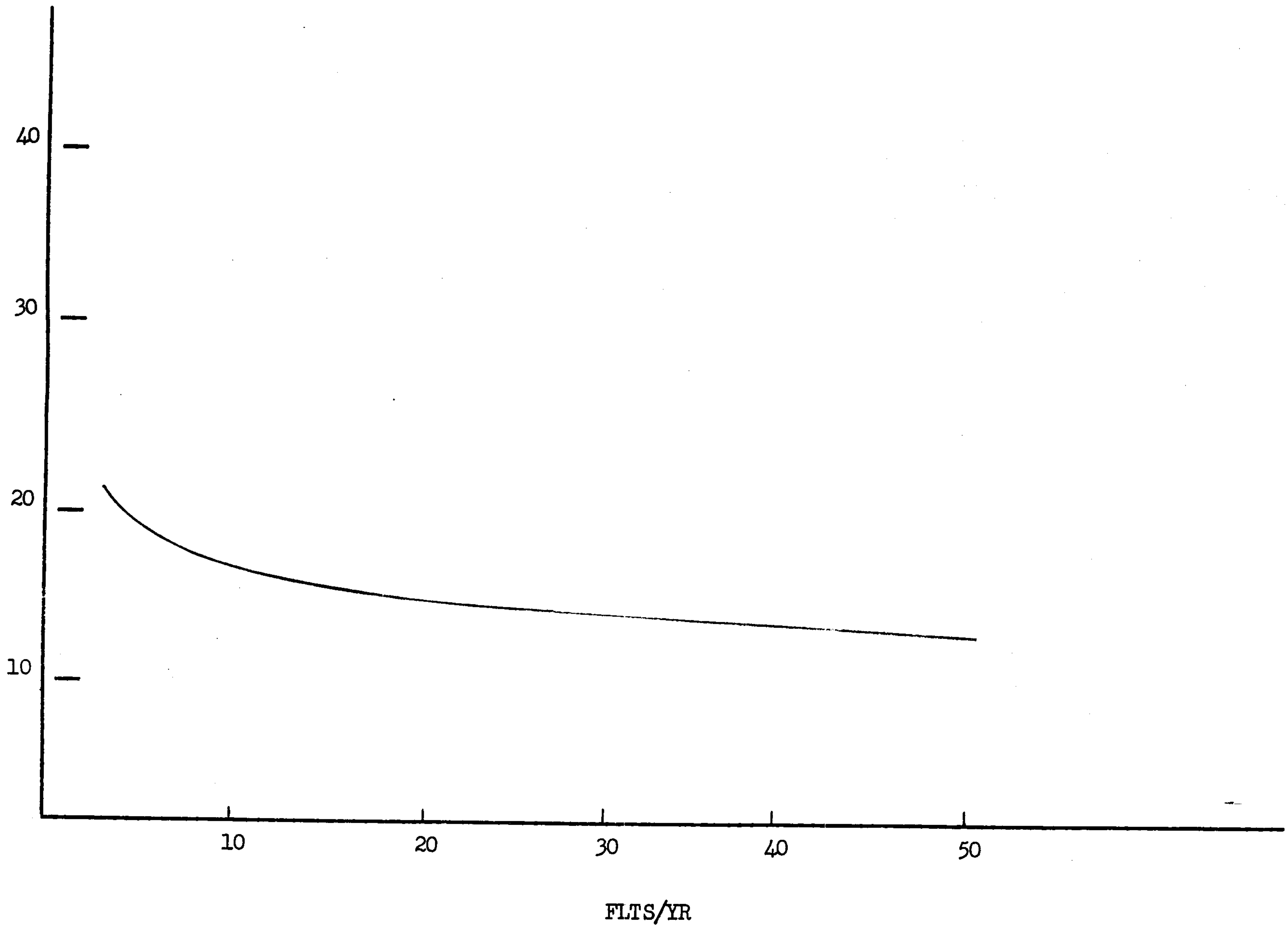


FIG. 6.4.5-1 MANPOWER REQTS FOR RECURRING FLT OPS AS FUNCTION OF NO. OF FLTS/YR

TABLE 6.4.5.1-1

CONFIGURATION 110A-1 IOC DEC '79

FLT OPS COST $M

		NON-RECURRING			RECURRING	TOTAL
		DDT&E Before / After	FLT TESTS Before / After	TOTAL Before / After		
NASA	MISSION PLANNING	5.53 / 2.90	0.79 / 0.12	6.32 / 3.02	(14/18)(8.71) = 6.70	16.040
	FLIGHT CONTROL	1.26 / 0.68	0.27 / 0.034	1.530/ .714	(9/35)(27.61)+(26/35)(14/18)(27.61) = 22.63	24.874
	FLIGHT EVALUATION	0.34 / 0.18	0.24 / 0.020	.580/ .200	(14/18)(1.86) = 1.43	2.210
	FLIGHT SOFTWARE	17.71 / 6.96	0 / 0	17.71 / 6.96	8.71	33.38
	TOTAL	24.84 /10.72	1.30 / 0.17	26.14 / 10.89	39.47	76.50
DOD	MISSION PLANNING	2.10 / 1.52	0 / 0	2.10 / 1.52	(14/18)(8.37) = 6.44	10.060
	FLIGHT CONTROL	0.65 / 0.60	0 / 0	0.65 / 0.60	(9/35)(26.48)+(26/35)(14/18)(26.48) = 21.71	22.960
	FLIGHT EVALUATION	0.36 / 0.22	0 / 0	0.36 / 0.22	(14/18)(1.80) = 1.38	1.960
	FLIGHT SOFTWARE	0 / 0	0 / 0	0 / 0	8.37	8.37
	TOTAL	3.11 / 2.34	0 / 0	3.11 / 2.34	37.900	43.350

NOTES:
(1) NASA 112 FLTS/11 YRS = 10.18 FLTS/YR AVERAGE → 14 MEN/FLT (REF. IS 18 MEN/FLT)
DOD 106 FLTS/11 YRS = 9.64 FLTS/YR AVERAGE → 14 MEN/FLT
(2) AUTONOMY LEVEL 3 DURING 1980 THROUGH 1990
(3) REPLACEMENTS FOR LOST FLIGHTS INCLUDED
(4) INCLUDES REDUCTIONS IN NOS. OF FLTS in 1980,81.

TABLE 6.4.5.2-1

CONFIGURATIONS 410AD-2 IOC DEC '83

FLT OPS COST $M

		NON-RECURRING						RECURRING	TOTAL
		DDT&E		FLT TESTS		TOTAL			
		Before IOC	After IOC	Before IOC	After IOC	Before IOC	After IOC		
N A S A	MISSION PLANNING	10.71 /	5.61	2.41 /	0.22	13.12 /	5.83	(12/18)(17.42) = 11.49	30.440
	FLIGHT CONTROL	0.86 /	0.45	0.32 /	0	1.18/	.45	(9/35)(20.31)+(26/35)(12/18)(20.31) = 15.02	16.650
	FLIGHT EVALUATION	0.54 /	0.28	0.58/	0.032	1.12/	.312	(12/18)(3.11) = 2.05	3.482
	FLIGHT SOFTWARE	29.73 /	11.68	0 /	0	29.73/	11.68	16.17	57.58
	TOTAL	41.84/	18.02	3.310/	0.252	45.15/	18.27	44.730	108.15
D O D	MISSION PLANNING	4.09/	2.95	0 /	0	4.09/	2.95	(13/18)(14.58) = 10.49	17.530
	FLIGHT CONTROL	0.42/	0.41	0 /	0	0.42/	0.41	(9/35)(16.95)+(26/35)(13/18)(16.95) = 13.21	14.040
	FLIGHT EVALUATION	0.57/	0.35	0 /	0	0.57/	0.35	(13/18)(2.6) = 1.87	2.790
	FLIGHT SOFTWARE	0 /	0	0 /	0	0 /	0	13.55	13.55
	TOTAL	5.080/	3.710	0 /	0	5.080/	3.710	39.12	47.910

NOTES: (1) NASA 138 FLTS/7 YEARS = 19.7 FLTS/YR AVERAGE → 12 MEN/FLT (REF. IS 18 MEN/FLT).
DOD 107 FLTS/7 YEARS = 15.3 FLTS/YR AVERAGE → 13 MEN/FLT.
(2) AUTONOMY LEVEL 2 THROUGHOUT 1984 THROUGH 1990
(3) REPLACEMENTS FOR LOST FLTS INCLUDED.
(4) INCLUDES REDUCTIONS IN FLTS DURING 1984,85.
(5) INCLUDES FLT TESTS OF MAIN STAGE AND AKS/DKS (SEPARATE FLT TEST).

TABLE 6.4.5.3-1

CONFIGURATION 310-3A → 310RE-3A

IOC DEC '79/DEC '83

		NON-RECURRING FLT OPS COST, $M					
		Initial Configuration 310-3A Autonomy Level 3: 1980,81,82 Autonomy Level 2: 1983			EVOLVED CONFIGURATION 310RE-3A (Autonomy Level 2)		
		DDT&E	FLT TESTS	TOTAL	DDT&E	FLT TESTS	TOTAL
NASA	MISSION PLANNING	5.22/4.52	0.75/0.30	5.97/4.82	2.88/1.51	0.42/0.06	3.30/1.57
	FLIGHT CONTROL	1.19/0.65	0.25/0.035	1.44/0.69	0.24/0.12	0.05/0.007	0.29/0.127
	FLIGHT EVALUATION	0.32/0.17	0.23/0.019	0.55/0.189	0.15/0.07	0.10/0.009	0.25/0.079
	FLIGHT SOFTWARE	16.72/8.00	0/0	16.72/8.00	8.00/3.14	0/0	8.00/3.14
	TOTAL	23.45/13.34	1.23/0.354	24.68/13.70	11.27/4.84	0.57/0.076	11.84/4.92
DOD	MISSION PLANNING	1.98/2.22	0/0	1.98/2.22	0.67/0.48	0/0	0.67/0.48
	FLIGHT CONTROL	0.61/0.57	0/0	0.61/0.57	0.07/0.07	0/0	0.07/0.07
	FLIGHT EVALUATION	0.34/0.21	0/0	0.34/0.21	0.11/0.06	0/0	0.11/0.06
	FLIGHT SOFTWARE	0/0	0/0	0/0	0/0	0/0	0/0
	TOTAL	2.93/3.00	0/0	2.93/3.00	0.85/0.61	0/0	0.85/0.61

TABLE 6.4.5.3-2

CONFIGURATION 310-3A → 310RE-3A | IOC DEC '79/DEC '83

RECURRING FLT OPS COST $M

		310-3A		310RE-3A	
N	MISSION PLANNING	(15/18)(2.57)=2.13		(12/18)(18.69)=12.33	
A	FLIGHT CONTROL	(9/35)(5.67)+(26/35)(15/18)(5.67)=3.45		(9/35)(25.26)+(26/35)(12/18)(25.26)=18.68	
S	FLIGHT EVALUATION	(15/18)(0.5)=.41		(12/18)(3.39)=2.23	
A	FLIGHT SOFTWARE	2.46		17.25	
	TOTALS		8.45		50.49
D	MISSION PLANNING	(15/18)(2.85)=2.36		(12/18)(14.6)=9.63	
O	FLIGHT CONTROL	(9/35)(6.03)+(26/35)(15/18)(6.03)=5.17		(9/35)(20.79)+(26/35)(12/18)(20.79)=15.37	
D	FLIGHT EVALUATION	(15/18)(0.55)=.45		(12/18) 2.63 = 1.73	
	FLIGHT SOFTWARE	2.72		13.44	
	TOTALS		10.70		40.17

NOTES: (1)

NASA	28	FLTS/4 YRS	=	7 FLTS/YR AVERAGE	→	15	MEN/FLT	310-3A
NASA	172	" 7 "	=	24.6 " " "		12	" "	310RE-3A
DOD	31	" 4 "	=	7.8 " " "		15	" "	310-3A
DOD	129	" 7 "	=	18.4 " " "		12	" "	310RE-3A

TABLE 6.4.5.3-3

CONFIGURATION 320A -3A → 320AE-3A

IOC DEC '79/DEC '83

		NON-RECURRING FLT OPS COST, $M					
		Initial Configuration 320A-3A Autonomy Level 3: 1980,81,82 Autonomy Level 2: 1983			EVOLVED CONFIGURATION 320AE-3A (Autonomy Level 2)		
		DDT&E	FLT TESTS	TOTAL	DDT&E	FLT TESTS	TOTAL
N A S A	MISSION PLANNING	7.88/6.82	1.13/0.47	9.01/7.29	1.88/0.99	0.27/0.04	2.15/1.03
	FLIGHT CONTROL	1.80/0.97	0.38/0.050	2.18/1.02	0.15/0.08	0.03/0.005	0.18/0.085
	FLIGHT EVALUATION	0.49/0.25	0.34/0.029	0.83/0.28	0.09/0.05	0.07/0.006	0.16/0.056
	FLIGHT SOFTWARE	25.24/12.05	0/0	25.24/12.05	5.22/2.05	0/0.	5.22/2.05
	TOTAL	35.41/20.09	1.85/0.55	37.26/20.64	7.34/3.17	0.37/0.051	7.71/3.22
D O D	MISSION PLANNING	2.99/3.93	0/0	2.99/3.93	0/0	0/0	0/0
	FLIGHT CONTROL	0.92/0.86	0/0	0.92/0.86	0/0	0/0	0/0
	FLIGHT EVALUATION	0.51/0.39	0/0	0.51/0.39	0/0	0/0	0/0
	FLIGHT SOFTWARE	0/0	0/0	0/0	0/0	0/0	0/0
	TOTAL	4.42/5.18	0/0	4.42/5.18	0/0	0/0	0/0

TABLE 6.4.5.3-4

CONFIGURATION 320A-3A → 320AE-3A IOC DEC '79/DEC '83

RECURRING FLT OPS COST $M

		320A-3A	320AE-3A
N	MISSION PLANNING	(14/18)(4.20)=3.27	(12/18)(19.31)=12.87
A	FLIGHT CONTROL	(9/35)(9.51)+(26/35)(14/18)(9.51)=7.94	(9/35)(22.69)+(26/35)(12/18)(22.69)=17.07
S	FLIGHT EVALUATION	(14/18)(0.84)=0.65	(12/18)(3.43)=2.29
A	FLIGHT SOFTWARE	4.03	17.50
	TOTALS	15.89	49.73
D	MISSION PLANNING	(15/18)(3.45)=2.87	(12/18)(16.46)=10.97
O	FLIGHT CONTROL	(9/35)(7.29)+(26/35)(15/18)(7.29)=6.39	(9/35)(19.22)+(26/35)(12/18)(19.22)=14.46
D	FLIGHT EVALUATION	(15/18)(0.68)=0.57	(12/18)(2.90)=1.93
	FLIGHT SOFTWARE	3.27	14.87
	TOTALS	13.10	42.23

NOTE: (1)

NASA	33 FLTS/4 YRS	=	8.3 FLTS/YR AVERAGE	→ 14 MEN/FLT	320A-3A
DOD	28 FLTS/4 YRS	=	7.0 FLTS/YR AVERAGE	→ 15 MEN/FLT	320A-3A
NASA	132 FLTS/7 YRS	=	18.9 FLTS/YR AVERAGE	→ 12 MEN/FLT	320AE-3A
DOD	107 FLTS/7 YRS	=	15.3 FLTS/YR AVERAGE	→ 12 MEN/FLT	320AE-3A

TABLE 6.4.5.4-1

CONFIGURATION 310-3B→310ARE-3B

IOC DEC '79/DEC '83

		NON-RECURRING FLT OPS COST, $M					
		Initial Configuration 310-3B Autonomy Level 3: 1980,81,82 Autonomy Level 2: 1983			EVOLVED CONFIGURATION 310ARE-3B (Autonomy Level 2)		
		DDT&E	FLT TESTS	TOTAL	DDT&E	FLT TESTS	TOTAL
NASA	MISSION PLANNING	5.22/4.52	0.75/0.30	5.97/4.82	3.01/1.57	0.44/0.06	3.45/1.63
	FLIGHT CONTROL	1.19/0.65	0.25/0.035	1.44/0.685	0.25/0.13	0.06/0.007	0.31/0.137
	FLIGHT EVALUATION	0.32/0.17	0.23/0.019	0.55/0.189	0.15/0.07	0.10/0.009	0.25/0.079
	FLIGHT SOFTWARE	16.72/7.98	0/0	16.72/7.98	8.35/3.27	0/0	8.35/3.27
	TOTAL	23.45/13.32	1.23/0.354	24.68/13.67	11.76/5.04	0.60/0.076	12.36/5.12
DOD	MISSION PLANNING	1.98/2.22	0/0	1.98/2.22	1.15/0.83	0/0	1.15/0.83
	FLIGHT CONTROL	0.61/0.57	0/0	0.61/0.57	0.12/0.12	0/0	0.12/0.12
	FLIGHT EVALUATION	0.34/0.21	0/0	0.34/0.21	0.16/0.10	0/0	0.16/0.10
	FLIGHT SOFTWARE	0/0	0/0	0/0	0/0	0/0	0/0
	TOTAL	2.93/3.00	0/0	2.93/3.00	2.26/1.05	0/0	2.26/1.05

TABLE 6.4.5.4-2

CONFIGURATION 310-3B → 310ARE-3B

IOC DEC '79/DEC '83

RECURRING FLT OPS COST $M

		310-3B	310ARE-3B
N	MISSION PLANNING	(15/18)(2.75)=2.28	(12/18)(20.47)=13.65
A	FLIGHT CONTROL	(9/35)(6.07)+(26/35)(15/18)(6.07)=5.21	(9/35)(23.94)+(26/35)(12/18)(23.94)=18.01
S	FLIGHT EVALUATION	(15/18)(0.55)=.45	(12/18)(3.67)=2.45
A	FLIGHT SOFTWARE	2.63	18.73
	TOTALS	10.57	52.84
D	MISSION PLANNING	(15/18)(2.85)=2.36	(12/18)(15.40)=10.16
O	FLIGHT CONTROL	(9/35)(6.03)+(26/35)(15/18)(6.03)=5.17	(9/35)(18.17)+(26/35)(12/18)(18.17)=13.44
D	FLIGHT EVALUATION	(15/18)(0.55)=.45	(12/18)(2.78)=1.83
	FLIGHT SOFTWARE	2.72	14.16
	TOTALS	10.70	39.59

NOTES: (1)

NASA	29/4 YRS	= 7.25 FLTS/YR AVERAGE	→ 15 MEN/FLT	310-3B
DOD	31/4 YRS	= 7.75 FLTS/YR AVERAGE	→ 15 MEN/FLT	310-3B
NASA	171/7 YRS	= 24.4 FLTS/YR AVERAGE	→ 12 MEN/FLT	310ARE-3B
DOD	134/7 YRS	= 19.1 FLTS/YR AVERAGE	→ 12 MEN/FLT	310ARE-3B

TABLE 6.4.5.4-3

CONFIGURATION 510A-3B → 510ADE-3B IOC DEC '79/DEC '83

		NON-RECURRING FLT OPS COST, $M					
		Initial Configuration 510A-3B Autonomy Level 3: 1980,81,82 Autonomy Level 2: 1983			EVOLVED CONFIGURATION 510ADE-3B (Autonomy Level 2)		
		DDT&E	FLT TESTS	TOTAL	DDT&E	FLT TESTS	TOTAL
N A S A	MISSION PLANNING	5.53/4.78	0.79/0.33	6.32/5.11	3.94/2.07	0.57/0.08	4.51/2.15
	FLIGHT CONTROL	1.26/0.68	0.27/0.034	1.53/0.714	0.32/0.16	0.07/0.009	0.39/0.169
	FLIGHT EVALUATION	0.34/0.18	0.24/0.020	0.58/0.20	0.20/0.10	0.14/0.012	0.34/0.112
	FLIGHT SOFTWARE	17.71/8.45	0/0	17.71/8.45	10.95/4.30	0/0	10.95/4.30
	TOTAL	24.84/14.09	1.30/0.384	26.14/14.47	15.41/6.63	0.78/0.101	16.19/6.73
D O D	MISSION PLANNING	2.10/2.34	0/0	2.10/2.34	1.51/1.09	0/0	1.51/1.09
	FLIGHT CONTROL	0.65/0.60	0/0	0.65/0.60	0.15/0.15	0/0	0.15/0.15
	FLIGHT EVALUATION	0.36/0.22	0/0	0.36/0.22	0.21/0.13	0/0	0.21/0.13
	FLIGHT SOFTWARE	0/0	0/0	0/0	0/0	0/0	0/0
	TOTAL	3.11/3.16	0/0	3.11/3.16	1.87/1.37	0/0	1.87/1.37

TABLE 6.4.5.4-4

CONFIGURATION 510A-3B → 510ADE-3B IOC DEC '79/DEC '83

RECURRING FLT OPS COST $M

		510A-3B	510ADE-3B
N	MISSION PLANNING	(14/18)(4.26)=3.31	(12/18)(19.08)=12.72
A	FLIGHT CONTROL	(9/35)(9.44)+(26/35)(14/18)(9.44)=7.88	(9/35)(22.17)+(26/35)(12/18)(22.17)=16.68
S	FLIGHT EVALUATION	(14/18)(0.82)=0.64	(12/18)(3.41)=2.27
A	FLIGHT SOFTWARE	4.09	17.76
	TOTALS	15.92	49.43
D	MISSION PLANNING	(14/18)(3.71)=2.89	(12/18)(16.67)=11.11
O	FLIGHT CONTROL	(9/35)(7.65)+(26/35)(14/18)(7.65)=6.39	(9/35)(19.38)+(26/35)(12/18)(19.38)=14.58
D	FLIGHT EVALUATION	(14/18)(0.72)=0.56	(12/18)(2.97)=1.98
	FLIGHT SOFTWARE	3.53	15.57
	TOTALS	13.37	43.24

NOTES: (1)

NASA	42 FLTS/4 YRS	=	10.5 FLTS/YR AVERAGE	→ 14 MEN/FLT	510A-3B
DOD	37 FLTS/4 YRS	=	9.3 FLTS/YR AVERAGE	→ 14 MEN/FLT	510A-3B
NASA	160 FLTS/7 YRS	=	22.9 FLTS/YR AVERAGE	→ 12 MEN/FLT	510ADE-3B
DOD	114 FLTS/7 YRS	=	16.3 FLTS/YR AVERAGE	→ 12 MEN/FLT	510ADE-3B

6.5.1 Velocity Package Sizing and Data

There were three ground rules for sizing the velocity packages. First, within an option the number of different sizes would be kept as small as possible. Cluster arrangements of a common size should be used to achieve variation in sizes where possible. Second, mission operations and profiles should not be unduly complicated. Third, the package should be sized to achieve required performance, not necessarily the maximum performance.

Figures 6.5.1.1, 6.5.1.2 and 6.5.1.3 show the deliverable payload and SRM sizes for planetary missions 21, 22, 23 and 24. The Tug thrust level was 7,500 lbs. The SRM ISP was 295.5 seconds with $\lambda' = 0.92$. The SRM's were two stage vehicles where each was sized to impart 1/2 of the total ΔV required. An overall structural weight of 3 percent of the initial weight and an avionics package of 2.6 lbs. was carried to burnout. The 'g' losses for the Tug were taken from a memo from F. Spurlock of Lewis Research Center. Losses of 1,600 Fps were added to the requirements for the SRM performance. These figures illustrate the wide range of SRM sizes which can satisfy these mission requirements. This characteristic allows for a basic kick stage to be sized for other missions and still be used efficiently in the high energy range of requirements.

The option 1 Tug/SRM can deliver $\approx$ 5,000 to 18,000 Fps, $\approx$ 2,460 lbs to 22,000 Fps and $\approx$ 1,690 lbs. to 24,000 Fps. Missions 21 and 23 are achievable and missions 22 and 24 are not achievable.

During the study it evolved that the round trip mission imposes the most difficult constraint on the SRM selection. For this reason, first considerations were given to this mission. The round trip performance to equatorial geosynchronous orbit vs. Tug/SRM ΔV split was derived for the four basic Tug AKS configurations. The results showed that the maximum performance occurs when the Tug imparts 8,000 $< \Delta$V Tug $<$ 9000 Fps and the SRM imparts 6000 $< \Delta$V SRM $<$ 5000 Fps. Moreover the difference in payload over these ranges is $<$ 50 lbs. Since the apogee burn requires $\approx$6000 Fps, from a mission simplicity standpoint the SRM should perform this total burn.

The ratio of the size of the SRM for the AKS and DKS is $\approx$ 2-1. In accordance with the first ground rule, this ratio was forced to be exactly 2-1 so that the ascent kick stage performs slightly less than the full apogee burn. Further the ascent and descent SRM consisted of a cluster of a smaller basic sized SRM. The delivery and retrieval performance of all the configurations were then evaluated using the SRM's sized for the round trip. Figures 6.5.1.4 and6.5.1.5 are the curves used to determine the sizes.

Figure 6.5.1.4 shows the total weight in orbit and SRM required to get it there vs. Δ V. These figures show Weight vs Δ V by Tug. Figure 6.5.1.5 shows the weight in orbit, the weight recovered and SRM weight required to recover the package. This curve is used to determine the recovery SRM characteristics.

Looking first at Figure 6.5.1.5 mark on the weight retrieved curve the required (payload plus avionics and structure). Then read the required retrieval SRM weight. If this SRM weight is a multiple of the round trip SRM it is a probable solution for the DKS. We would then read from the weight in orbit curve the weight which was delivered.

Going to Figure 6.5.1.4 to the same weight in orbit, read the required SRM weight to have delivered the package. If this weight is a multiple of the round trip basic SRM it would represent a solution. Assuming it didn't happen, we itterate going back to Figure 6.5.1.5 take a slightly larger or smaller (payload plus avionics and structure). Read the corresponding required SRM. If it is a multiple, continue to figure b and repeat the process. It happens sometimes that there is no solution which is a multiple of the basic round trip SRM. In this case, a new SRM size is tried and the procedure is repeated. A similar process is used for the deploy and double deploy missions. Tables 6.1.2.1 thru 6.1.3.7 show the selected kick stage sizes and performance for all options.

SRM SIZING CURVES

510ADE-3B

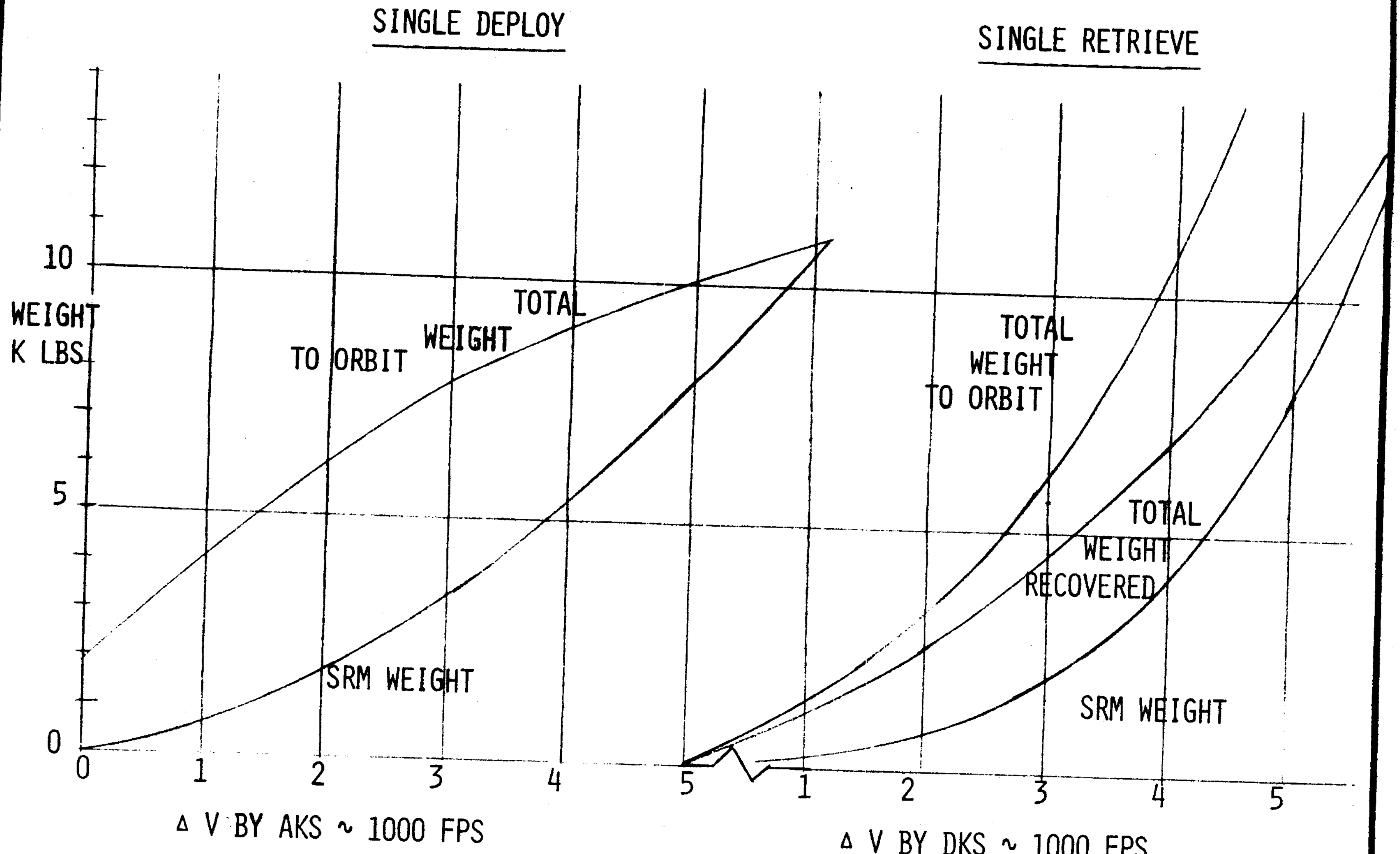


FIG. 6.5.1.4

FIG. 6.5.1.5

GRUMMAN

RECOVERY OF TUG FOR HIGH ENERGY PLANETARY MISSIONS

(REF. F. SPURLOCK, LERC "PERFORMANCE DATA FOR CRYOGENIC AND STORABLE TUGS FOR EARTH-ESCAPE MISSIONS")

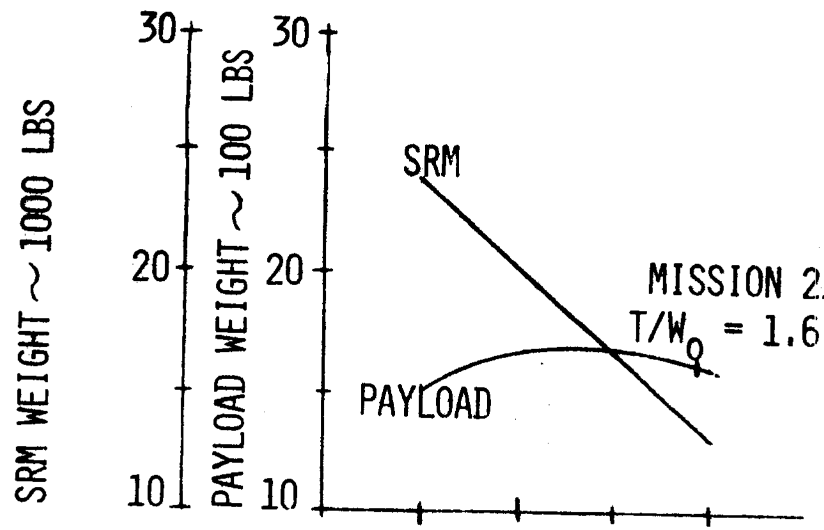
C_3=106.8 KM^2/SEC^2
(ΔV=24000FPS)

MISSION 21
P/L=1600 LBS

MISSION 22
P/L = 2500 LBS (NOT ACHIEVABLE)

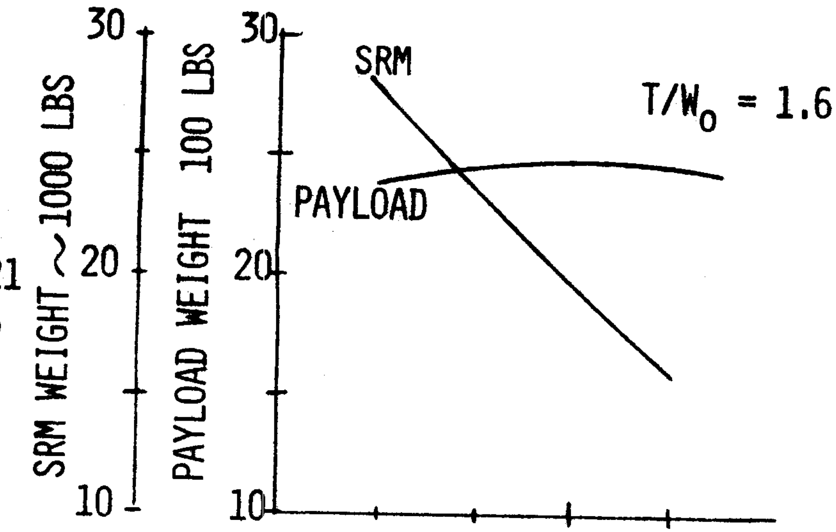
C_3=88.9 KM^2/SEC^2
(ΔV=22000 FPS)

MISSION 24
P/L=3300 LBS (NOT ACHIEVABLE)



TUG STAGING ΔV

FIG. 6.5.1.1



TUG STAGING ΔV

FIG. 6.5.1.2

GRUMMAN

CONFIGURATION 110A

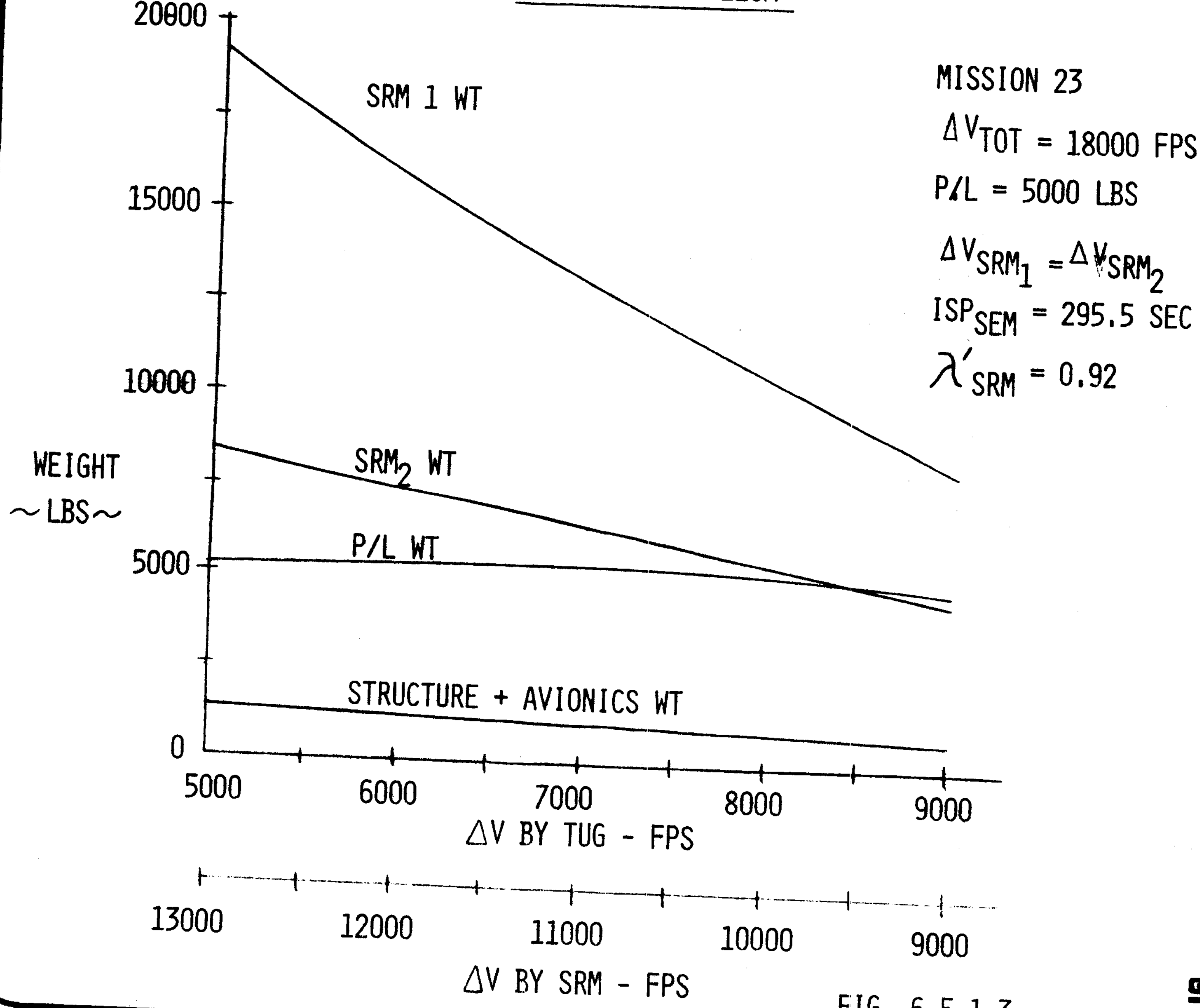


FIG. 6.5.1.3

GRUMMAN

6.5.2 Expendable Tug vs. Tug-To-Tug On-Orbiter Assembly

6.5.2.1 Objective: Determine most cost effective way for storable tug to perform high energy missions.

- Expend Tug
- Dual Shuttle launch and recover of both tugs.

6.5.2.2 Guidelines

- o Baseline used for programmatic and cost analyses was expendable Tug
- o Expendable Tugs were required only to perform the NASA high energy planetary missions.
- o For programs costed, no. of Tugs expended varied from 8 (for programs with AKS) to 17 (for programs without AKS)
- o No. of expended Tugs directly affected Tug fleet size
- o Dual storable Tug flights also required AKS to capture high energy planetary missions.

6.5.2.3 Operational Cost Comparison

- o Expended Tug Equivalent OPS cost = (OPS Cost of one shuttle Flight)+(Average OPS Cost of one Expended Tug Flight) = ($10.5M) + ($10.7M) = $21.2M
- o Tug-to-Tug on-orbit assembly Equiv. OPS Cost = (OPS Cost of two Shuttle Flights) + (OPS Cost of one reusable Tug flight)+(Average OPS cost of one reusable Tug + AKS flight) = ($21M) + ($1.1M) + ($2.314)=$24.4M.
- o Therefore expendable Tug results in $3.2M lower equivalent OPS cost/flight than tug-to-tug on-orbit assembly.

6.5.2.4 Development Cost Comparison

- o Tug program designed to accomodate Tug-to-Tug on-orbit OPS would increase DDT&E costs.
- o Areas of increased DDT&E Cost are:
  - Interstage and rearward docking hardware (similar to 2-stage tug requirements)
  - Expanded vehicle ground test/flight test program
  - Modifications to on-board/ground based flight software
  - Expanded flight OPS control facility and GSE

6.5.2.5 Summary

- o Expending Tugs for high energy missions results in both lower OPS cost and lower DDT&E cost than Tug-to-Tug on-orbit assembly.
- o Therefore, present baseline (expending Tug) is cost effective.

6.5.3 Multi Deployment Analysis

6.5.3.1 Ground Rules

The first and second packages in the multiple-deployment schemes were separated by 60 degrees central angle. When a third payload was deployed it was placed with the second payload with no additional allocation for phasing time or ΔV budget. All packages on a Tug were assumed to be the same weight. For the missions augmented with kick stages the total apogee burn with 28.5 degrees plane change was performed by the kick stage.

6.5.3.2 ΔV Budgets

The ΔV budgets for this study were selected to closely reflect the previous multi-deployment budgets. The ascent portions are identical. The on-orbit allocations were modified to perform the 60 degree phasing maneuver. For the missions augmented with kick stages the descent budget was reduced to reflect a smaller nodal regression penalty for the 60 degree spacing. These budgets are tabulated in Table 1.

6.5.3.3 Summary of Performance

A tabulation of the performance capability of the four options is shown in Table II. The data includes the NASA and DOD performance for level II and level IV autonomy.

TABLE 1

MULTIPLE DEPLOY ΔV BUDGETS					
PROP. SYS.	MISSION LEG	SINGLE STAGE		SINGLE + AKS	
		THRUST ∼ LBS		THRUST ∼ LBS	
		7500	1200	7500	1200
MPS	OUTBOUND	14018	13967	8098	8034
AKS	OUTBOUND	-	-	6014	6011
MPS	ON-ORBIT	292	292	432	432
MPS	RETURN	13891	13885	9241	9235

SUMMARY TABLE

OPTION	CONFIGURATION	NASA		DOD	
		DEPLOY-2	DEPLOY-3	DEPLOY-2	DEPLOY-3
1	110A-1				
	CORE ALONE	2007	-		
	CORE + AKS	4050			
2	410 AD-2				
	CORE ALONE	2174	1443	2118	1406
	CORE + AKS	4685	3030	4669	3018
3A	310 RE-3A				
	LEVEL III AUTONOMY	2430	1612	2374	1575
	LEVEL II AUTONOMY	2213	1468	2159	1432
3A	320 AE-3A				
	SLING SHOT	2375	1540	-	-
	REVERSE SLINGSHOT	2770	1840	-	-
	LOWER STAGE + AKS	5642	3733		
	LOWER STAGE + ADKS	2847	1883		
3B	310 ARE-3B				
	LEVEL III AUTON-CORE	2380	1580	2325	1543
	LEVEL II AUTON-CORE	2165	1436	2109	1399
	LEVEL II AUTON-CORE + AKS	4684	3028	4667	3017
3B	510 ADE-3B				
	LEVEL III AUTON-CORE	1359	901	1300	862
	LEVEL III AUTON-CORE + AKS	4388	2832	4371	2821
	LEVEL II AUTON-CORE	1134	752	1075	713
	LEVEL II AUTON-CORE + AKS	4322	2788	9795	4305

6.5.4 On-Orbit Servicing

The summary of weight and performance for the Service 1 and 2 missions is given below:

Type of Flt	MPS Propellant (lb)	APS Propellant (lb)	Weight Payload (lb)
Service 1 (Discard Parts)	57512.7	990.6	Parts 1,2,3,4 = 171.6 each
Service 2 (Bring Back Parts)	57938.0	1019.6	Parts 1,2,3,4 = 24 each

Fuel Cell Reactant and Start/Stop Losses were input into the weight time history runs as follows:

	S1	S2
Fuel Cell Reactant	306	405
Start/Stop Losses	90	90

In the runs, the fuel cell reactant plus start/stop losses sum was divided by 4 and each of the 4 parts was discretely dumped at 4 different parts of the mission, 2 on the up leg and 2 on the down leg.

In the Service 1 mission, four 5000 lb. payloads dispersed in geosynchronous orbit were serviced. Each part that was replaced was discarded before moving onto the next payload. In the Service 2 mission, four 5000 lb payloads dispersed in geosynchronous orbit were serviced, but in this case each part that was replaced was retained and brought back to the Shuttle. The time histories for these 2 service missions follow.

TUG DELTA-V BUDGET

CONFIG. CONCEPT. 410AD-2

1-STG SERVICES 4 PL--REPL PARTS & DISC

		DV MAIN	DV APS
		********	********
1	THRUST ST	0.0	0.0
6	TOI	7424.0	0.0
11	MCC	0.0	22.0
15	MOI	5874.0	0.0
20	TPI	30.0	0.0
23	MCC	0.0	0.1
26	TPF	0.0	35.0
29	DOCK PL 1	0.0	8.0
35	THRUST FR PL 1	0.0	10.0
39	POI	47.0	0.0
43	MCC	0.0	0.2
47	MOI	47.0	0.0
51	TPI	30.0	0.0
54	MCC	0.0	0.1
57	TPF	0.0	35.0
60	DOCK PL 2	0.0	8.0
66	THRUST FR PL 2	0.0	10.0
70	POI	110.0	0.0
74	MCC	0.0	0.3
78	MOI	110.0	0.0
82	TPI	30.0	0.0
85	MCC	0.0	0.1
88	TPF	0.0	35.0
91	DOCK PL 3	0.0	8.0
97	THRUST FR PL 3	0.0	10.0
**	POI	54.0	0.0
**	MCC	0.0	0.2
**	MOI	54.0	0.0
**	TPI	30.0	0.0
**	MCC	0.0	0.1
**	TPF	0.0	35.0
**	DOCK PL 4	0.0	8.0
**	THRUST FR PL 4	0.0	10.0
**	TOI	5874.0	0.0
**	MCC	0.0	17.0
**	POI	3750.0	0.0
**	MCC	0.0	11.0
**	CIRC	4376.0	0.0
**	ADJ	0.0	13.0
**	CONTINGENCY 1.7(	473.6	0.0
		********	********
TOTALS		28313.6	276.1

TUG WEIGHT HISTORY

CONFIG. CONCEPT 410AD-2

1-STG SERVICES 4 PL--REPL PARTS & DISC

			WT BEF		DLT PAY		WT AFT		PRO-MAIN		PRO-APS
			********		********		********		********		********
1	THRUST ST	*	63721.0	*	0.0	*	63721.0	*	0.0	*	0.0
2	NB RELEASE ST	*	63721.0	*	0.0	*	63721.0	*	0.0	*	0.0
3	WB	*	63721.0	*	0.0	*	63720.9	*	0.0	*	0.0
4	S_EW IMU TOI	*	63720.9	*	0.0	*	63701.7	*	0.0	*	19.3
5	NB IMU TOI	*	63701.7	*	0.0	*	63701.6	*	0.0	*	0.1
6	TOI	*	63701.6	*	0.0	*	32186.0	*	31515.6	*	0.0
7	FC REACT & MPS VENT	*	32186.0	*	0.0	*	32087.0	*	0.0	*	0.0
8	WB	*	32087.0	*	0.0	*	32086.8	*	0.0	*	0.2
9	SLEW MCC	*	32086.8	*	0.0	*	32081.9	*	0.0	*	4.8
10	NB MCC	*	32081.9	*	0.0	*	32081.9	*	0.0	*	0.0
11	MCC	*	32081.9	*	0.0	*	31987.5	*	0.0	*	94.4
12	WB	*	31987.5	*	0.0	*	31987.2	*	0.0	*	0.2
13	S_EW IMU MOI	*	31987.2	*	0.0	*	31977.6	*	0.0	*	9.7
14	NB IMU MOI	*	31977.6	*	0.0	*	31977.4	*	0.0	*	0.2
15	MOI	*	31977.4	*	0.0	*	18632.0	*	13345.4	*	0.0
16	FC REACT & MPS VENT	*	18632.0	*	0.0	*	18533.0	*	0.0	*	0.0
17	WB	*	18533.0	*	0.0	*	18531.4	*	0.0	*	1.6
18	S_EW TRACK	*	18531.4	*	0.0	*	18517.4	*	0.0	*	14.0
19	NB TRACK	*	18517.4	*	0.0	*	18516.0	*	0.0	*	1.5
20	TPI	*	18516.0	*	0.0	*	18465.0	*	51.0	*	0.0
21	S_EW TRACK	*	18465.0	*	0.0	*	18451.0	*	0.0	*	13.9
22	NB TRACK	*	18451.0	*	0.0	*	18450.2	*	0.0	*	0.8
23	MCC	*	18450.2	*	0.0	*	18449.9	*	0.0	*	0.2
24	S_EW TRACK	*	18449.9	*	0.0	*	18436.0	*	0.0	*	13.9
25	NB TRACK	*	18436.0	*	0.0	*	18435.1	*	0.0	*	0.8
26	TPF	*	18435.1	*	0.0	*	18348.9	*	0.0	*	86.2
27	S_EW DOCK	*	18348.9	*	0.0	*	18321.1	*	0.0	*	27.7
28	NB DOCK	*	18321.1	*	0.0	*	18320.9	*	0.0	*	0.2
29	DOCK PL 1	*	18320.9	*	0.0	*	18301.3	*	0.0	*	19.6
30	ADD PL 1	*	18301.3	*	5000.0	*	23301.3	*	0.0	*	0.0
31	WB	*	23301.3	*	0.0	*	23301.0	*	0.0	*	0.3
32	SLEW DEPLOY	*	23301.0	*	0.0	*	23297.5	*	0.0	*	3.5
33	NB DEPLOY	*	23297.5	*	0.0	*	23297.5	*	0.0	*	0.0
34	DROP PL 1	*	23297.5	*	-5171.6	*	18125.9	*	0.0	*	0.0
35	THRUST FR PL 1	*	18125.9	*	0.0	*	18101.6	*	0.0	*	24.3
36	WB	*	18101.6	*	0.0	*	18101.5	*	0.0	*	0.1
37	S_EW IMU POI	*	18101.5	*	0.0	*	18100.2	*	0.0	*	1.3
38	NB IMU POI	*	18100.2	*	0.0	*	18100.1	*	0.0	*	0.1
39	POI	*	18100.1	*	0.0	*	18022.1	*	78.1	*	0.0
40	WB	*	18022.1	*	0.0	*	18003.7	*	0.0	*	18.4
41	S_EW MCC	*	18003.7	*	0.0	*	18003.1	*	0.0	*	0.7
42	NB MCC	*	18003.1	*	0.0	*	18003.0	*	0.0	*	0.0
43	MCC	*	18003.0	*	0.0	*	18002.5	*	0.0	*	0.5
44	WB	*	18002.5	*	0.0	*	17984.1	*	0.0	*	18.4
45	S_EW IMU MOI	*	17984.1	*	0.0	*	17982.8	*	0.0	*	1.3
46	NB IMU MOI	*	17982.8	*	0.0	*	17982.8	*	0.0	*	0.1
47	MOI	*	17982.8	*	0.0	*	17905.2	*	77.6	*	0.0
48	WB	*	17905.2	*	0.0	*	17903.1	*	0.0	*	2.1
49	S_EW TRACK	*	17903.1	*	0.0	*	17899.8	*	0.0	*	3.3
50	NB TRACK	*	17899.8	*	0.0	*	17898.3	*	0.0	*	1.5
51	TPI	*	17898.3	*	0.0	*	17849.0	*	49.3	*	0.0
52	S_EW TRACK	*	17849.0	*	0.0	*	17845.7	*	0.0	*	3.2
53	NB TRACK	*	17845.7	*		*	17844.2	*	0.0	*	1.5
54	MCC	*	17844.2	*	0.0	*	17844.0	*	0.0	*	0.2

55	S_EW TRACK	17844.0	0.0	17840.7	0.0	3.2
56	NB TRACK	17840.7	0.0	17839.2	0.0	1.5
57	TPF	17839.2	0.0	17755.8	0.0	83.5
58	S_EW DOCK	17755.8	0.0	17749.3	0.0	6.5
59	NB DOCK	17749.3	0.0	17749.0	0.0	0.3
60	DOCK PL 2	17749.0	0.0	17730.0	0.0	19.0
61	ADD PL 2	17730.0	5000.0	22730.0	0.0	0.0
62	WB	22730.0	0.0	22729.7	0.0	0.3
63	SLEW DEPLOY	22729.7	0.0	22726.3	0.0	3.4
64	NB DEPLOY	22726.3	0.0	22726.3	0.0	0.0
65	DROP PL 2	22726.3	-5171.6	17554.7	0.0	0.0
66	THRUST FR PL 2	17554.7	0.0	17531.2	0.0	23.5
67	WB	17531.2	0.0	17531.1	0.0	0.1
68	S_EW IMU POI	17531.1	0.0	17529.8	0.0	1.3
69	NB IMU POI	17529.8	0.0	17529.7	0.0	0.1
70	POI	17529.7	0.0	17353.3	176.4	0.0
71	WB	17353.3	0.0	17318.5	0.0	34.8
72	SLEW MCC	17318.5	0.0	17317.8	0.0	0.6
73	NB MCC	17317.8	0.0	17317.8	0.0	0.0
74	MCC	17317.8	0.0	17317.1	0.0	0.7
75	WB	17317.1	0.0	17282.2	0.0	34.9
76	S_EW IMU MOI	17282.2	0.0	17280.9	0.0	1.3
77	NB IMU MOI	17280.9	0.0	17280.9	0.0	0.1
78	MOI	17280.9	0.0	17106.9	173.9	0.0
79	WB	17106.9	0.0	17104.7	0.0	2.2
80	S_EW TRACK	17104.7	0.0	17101.6	0.0	3.1
81	NB TRACK	17101.6	0.0	17100.0	0.0	1.6
82	TPI	17100.0	0.0	17052.9	47.1	0.0
83	S_EW TRACK	17052.9	0.0	17049.8	0.0	3.1
84	NB TRACK	17049.8	0.0	17048.2	0.0	1.6
85	MCC	17048.2	0.0	17048.0	0.0	0.2
86	S_EW TRACK	17048.0	0.0	17044.9	0.0	3.1
87	NB TRACK	17044.9	0.0	17043.3	0.0	1.6
88	TPF	17043.3	0.0	16963.6	0.0	79.7
89	S_EW DOCK	16963.6	0.0	16957.4	0.0	6.2
90	NB DOCK	16957.4	0.0	16957.1	0.0	0.3
91	DOCK PL 3	16957.1	0.0	16938.9	0.0	18.2
92	ADD PL 3	16938.9	5000.0	21938.9	0.0	0.0
93	WB	21938.9	0.0	21938.6	0.0	0.3
94	SLEW DEPLOY	21938.6	0.0	21935.3	0.0	3.3
95	NB DEPLOY	21935.3	0.0	21935.3	0.0	0.0
96	DROP PL 3	21935.3	-5171.6	16763.7	0.0	0.0
97	THRUST FR PL 3	16763.7	0.0	16741.2	0.0	22.4
98	WB	16741.2	0.0	16741.1	0.0	0.1
99	S_EW IMU POI	16741.1	0.0	16739.9	0.0	1.2
**	NB IMU POI	16739.9	0.0	16739.8	0.0	0.1
**	POI	16739.8	0.0	16656.9	82.9	0.0
**	WB	16656.9	0.0	16637.1	0.0	19.8
**	S_EW MCC	16637.1	0.0	16636.5	0.0	0.6
**	NB MCC	16636.5	0.0	16636.4	0.0	0.0
**	MCC	16636.4	0.0	16636.0	0.0	0.4
**	WB	16636.0	0.0	16616.2	0.0	19.8
**	S_EW IMU MOI	16616.2	0.0	16614.9	0.0	1.2
**	NB IMU MOI	16614.9	0.0	16614.9	0.0	0.1
**	MOI	16614.9	0.0	16532.6	82.3	0.0
**	WB	16532.6	0.0	16530.2	0.0	2.3
**	S_EW TRACK	16530.2	0.0	16527.2	0.0	3.0
**	NB TRACK	16527.2	0.0	16525.6	0.0	1.6
**	TPI	16525.6	0.0	16480.1	45.5	0.0
**	S_EW TRACK	16480.1	0.0	16477.1	0.0	3.0
**	NB TRACK	16477.1	0.0	16475.4	0.0	1.6
**	MCC	16475.4	0.0	16475.2	0.0	0.2
**	S_EW TRACK	16475.2	0.0	16472.2	0.0	3.0
**	NB TRACK	16472.2	0.0	16470.6	0.0	1.6
**	TPF	16470.6	0.0	16393.5	0.0	77.0
**	S_EW DOCK	16393.5	0.0	16387.6	0.0	6.0

**	NB DOCK	* 16387.6 *	0.0 *	16387.2 *	0.0 *	0.3
**	DOCK PL 4	* 16387.2 *	0.0 *	16369.7 *	0.0 *	17.6
**	ADD PL 4	* 16369.7 *	5000.0 *	21369.7 *	0.0 *	0.0
**	WB	* 21369.7 *	0.0 *	21369.4 *	0.0 *	0.3
**	SLEW DEPLOY	* 21369.4 *	0.0 *	21366.2 *	0.0 *	3.2
**	NB DEPLOY	* 21366.2 *	0.0 *	21366.1 *	0.0 *	0.1
**	DROP PL 4	* 21366.1 *	-5171.6 *	16194.5 *	0.0 *	0.0
**	THRUST FR PL 4	* 16194.5 *	0.0 *	16172.8 *	0.0 *	21.7
**	WB	* 16172.8 *	0.0 *	16169.9 *	0.0 *	2.9
**	S_EW IMU TOI	* 16169.9 *	0.0 *	16168.7 *	0.0 *	1.2
**	NB IMU TOI	* 16168.7 *	0.0 *	16168.3 *	0.0 *	0.4
**	TOI	* 16168.3 *	0.0 *	9420.6 *	6747.6 *	0.0
**	FC REACT & MPS VENT	* 9420.6 *	0.0 *	9321.6 *	0.0 *	0.0
**	WB	* 9321.6 *	0.0 *	9320.6 *	0.0 *	1.0
**	S_EW MCC	* 9320.6 *	0.0 *	9320.3 *	0.0 *	0.3
**	NB MCC	* 9320.3 *	0.0 *	9320.2 *	0.0 *	0.1
**	MCC	* 9320.2 *	0.0 *	9299.0 *	0.0 *	21.2
**	WB	* 9299.0 *	0.0 *	9298.0 *	0.0 *	1.0
**	S_EW IMU POI	* 9298.0 *	0.0 *	9297.3 *	0.0 *	0.7
**	NB IMU POI	* 9297.3 *	0.0 *	9296.8 *	0.0 *	0.5
**	POI	* 9296.8 *	0.0 *	6585.3 *	2711.5 *	0.0
**	FC REACT & MPS VENT	* 6585.3 *	0.0 *	6486.3 *	0.0 *	0.0
**	WB	* 6486.3 *	0.0 *	6485.4 *	0.0 *	0.8
**	S_EW MCC	* 6485.4 *	0.0 *	6485.2 *	0.0 *	0.2
**	NB MCC	* 6485.2 *	0.0 *	6485.1 *	0.0 *	0.1
**	MCC	* 6485.1 *	0.0 *	6475.5 *	0.0 *	9.5
**	WB	* 6475.5 *	0.0 *	6474.7 *	0.0 *	0.8
**	S_EW IMU CIRC	* 6474.7 *	0.0 *	6474.2 *	0.0 *	0.5
**	NB IMU CIRC	* 6474.2 *	0.0 *	6473.4 *	0.0 *	0.8
**	CIRC	* 6473.4 *	0.0 *	4328.9 *	2144.5 *	0.0
**	WB	* 4328.9 *	0.0 *	4328.7 *	0.0 *	0.1
**	SLEW ADJ	* 4328.7 *	0.0 *	4328.6 *	0.0 *	0.2
**	NB ADJ	* 4328.6 *	0.0 *	4328.4 *	0.0 *	0.2
**	ADJ	* 4328.4 *	0.0 *	4320.9 *	0.0 *	7.5
**	WB	* 4320.9 *	0.0 *	4320.7 *	0.0 *	0.1
**	S_EW EOS CAPTURE ST	* 4320.7 *	0.0 *	4320.6 *	0.0 *	0.2
**	NB EOS CAPTURE ST	* 4320.6 *	0.0 *	4319.0 *	0.0 *	1.6
**	CONTINGENCY 1.7(	* 4319.0 *	0.0 *	4135.0 *	184.1 *	0.0
					********	********
TOTALS					57512.7	990.6

TUG DELTA-V BUDGET

CONFIG. CONCEPT 410AD-2

1-STG SRVCS 4 PL IN GEOS--BRG PRTS 8K

			DV MAIN		DV APS
			********		********
1	THRUST ST	*	0.0	*	0.0
6	TDI	*	7424.0	*	0.0
11	MCC	*	0.0	*	22.0
15	MDI	*	5874.0	*	0.0
20	TPI	*	30.0	*	0.0
23	MCC	*	0.0	*	0.1
26	TPF	*	0.0	*	35.0
29	DOCK PL 1	*	0.0	*	8.0
35	THRUST FR PL 1	*	0.0	*	10.0
39	PDI	*	47.0	*	0.0
43	MCC	*	0.0	*	0.2
47	MDI	*	47.0	*	0.0
51	TPI	*	30.0	*	0.0
54	MCC	*	0.0	*	0.1
57	TPF	*	0.0	*	35.0
60	DOCK PL 2	*	0.0	*	8.0
66	THRUST FR PL 2	*	0.0	*	10.0
70	PDI	*	110.0	*	0.0
74	MCC	*	0.0	*	0.3
78	MDI	*	110.0	*	0.0
82	TPI	*	30.0	*	0.0
85	MCC	*	0.0	*	0.1
88	TPF	*	0.0	*	35.0
91	DOCK PL 3	*	0.0	*	8.0
97	THRUST FR PL 3	*	0.0	*	10.0
**	PDI	*	54.0	*	0.0
**	MCC	*	0.0	*	0.2
**	MDI	*	54.0	*	0.0
**	TPI	*	30.0	*	0.0
**	MCC	*	0.0	*	0.1
**	TPF	*	0.0	*	35.0
**	DOCK PL 4	*	0.0	*	8.0
**	THRUST FR PL 4	*	0.0	*	10.0
**	TDI	*	5874.0	*	0.0
**	MCC	*	0.0	*	17.0
**	PDI	*	3750.0	*	0.0
**	MCC	*	0.0	*	11.0
**	CIRC	*	4376.0	*	0.0
**	ADJ	*	0.0	*	13.0
**	CONTINGENCY 1.7(	*	473.6	*	0.0
			********		********
TOTALS			28313.6		276.1

TUG WEIGHT HISTORY

CONFIG. CONCEPT 410AD-2

1-STG SRVCS 4 PL IN GEOS--BRG PRTS BK

		WT BEF	DLT PAY	WT AFT	PRO-MAIN	PRO-APS
1	THRUST ST	63721.0	0.0	63721.0	0.0	0.0
2	NB RELEASE ST	63721.0	0.0	63721.0	0.0	0.0
3	WB	63721.0	0.0	63720.9	0.0	0.0
4	SLEW IMU TOI	63720.9	0.0	63698.7	0.0	22.2
5	NB IMU TOI	63698.7	0.0	63698.6	0.0	0.1
6	TOI	63698.6	0.0	32184.5	31514.1	0.0
7	FC REACT & MPS VENT	32184.5	0.0	32060.8	0.0	0.0
8	WB	32060.8	0.0	32060.5	0.0	0.2
9	SLEW MCC	32060.5	0.0	32054.9	0.0	5.6
10	NB MCC	32054.9	0.0	32054.9	0.0	0.0
11	MCC	32054.9	0.0	31960.6	0.0	94.3
12	WB	31960.6	0.0	31960.3	0.0	0.2
13	SLEW IMU MOI	31960.3	0.0	31949.2	0.0	11.1
14	NB IMU MOI	31949.2	0.0	31949.0	0.0	0.2
15	MOI	31949.0	0.0	18615.5	13333.5	0.0
16	FC REACT & MPS VENT	18615.5	0.0	18491.8	0.0	0.0
17	WB	18491.8	0.0	18490.2	0.0	1.6
18	SLEW TRACK	18490.2	0.0	18474.1	0.0	16.1
19	NB TRACK	18474.1	0.0	18472.6	0.0	1.5
20	TPI	18472.6	0.0	18421.7	50.9	0.0
21	SLEW TRACK	18421.7	0.0	18405.7	0.0	16.0
22	NB TRACK	18405.7	0.0	18404.8	0.0	0.8
23	MCC	18404.8	0.0	18404.6	0.0	0.2
24	SLEW TRACK	18404.6	0.0	18388.6	0.0	16.0
25	NB TRACK	18388.6	0.0	18387.7	0.0	0.8
26	TPF	18387.7	0.0	18301.7	0.0	86.0
27	SLEW DOCK	18301.7	0.0	18269.8	0.0	31.9
28	NB DOCK	18269.8	0.0	18269.6	0.0	0.2
29	DOCK PL 1	18269.6	0.0	18250.0	0.0	19.6
30	ADD PL 1	18250.0	5000.0	23250.0	0.0	0.0
31	WB	23250.0	0.0	23249.8	0.0	0.3
32	SLEW DEPLOY	23249.8	0.0	23245.7	0.0	4.0
33	NB DEPLOY	23245.7	0.0	23245.7	0.0	0.0
34	DROP PL 1	23245.7	-5000.0	18245.7	0.0	0.0
35	THRUST FR PL 1	18245.7	0.0	18221.2	0.0	24.4
36	WB	18221.2	0.0	18221.2	0.0	0.1
37	SLEW IMU POI	18221.2	0.0	18219.4	0.0	1.7
38	NB IMU POI	18219.4	0.0	18219.4	0.0	0.1
39	POI	18219.4	0.0	18140.8	78.6	0.0
40	WB	18140.8	0.0	18123.9	0.0	16.9
41	SLEW MCC	18123.9	0.0	18123.0	0.0	0.9
42	NB MCC	18123.0	0.0	18123.0	0.0	0.0
43	MCC	18123.0	0.0	18122.5	0.0	0.5
44	WB	18122.5	0.0	18105.5	0.0	17.0
45	SLEW IMU MOI	18105.5	0.0	18103.8	0.0	1.7
46	NB IMU MOI	18103.8	0.0	18103.7	0.0	0.1
47	MOI	18103.7	0.0	18025.7	78.1	0.0
48	WB	18025.7	0.0	18023.7	0.0	2.0
49	SLEW TRACK	18023.7	0.0	18019.4	0.0	4.3
50	NB TRACK	18019.[illegible]	[illegible]	18018.0	0.0	1.4
51	TPI	18018.0	0.0	17968.4	49.6	0.0
52	SLEW TRACK	17968.4	0.0	17964.1	0.0	4.3
53	NB TRACK	17964.1	0.0	17962.8	0.0	1.4
54	MCC	17962.8	0.0	17962.5	0.0	0.2

55	S_EW TRACK	17962.5	0.0	17958.3	0.0	4.2
56	NB TRACK	17958.3	0.0	17956.9	0.0	1.4
57	TPF	17956.9	0.0	17872.9	0.0	84.0
58	S_EW DOCK	17872.9	0.0	17864.4	0.0	8.5
59	NB DOCK	17864.4	0.0	17864.1	0.0	0.3
60	DOCK PL 2	17864.1	0.0	17845.0	0.0	19.1
61	ADD PL 2	17845.0	5000.0	22845.0	0.0	0.0
62	WB	22845.0	0.0	22844.7	0.0	0.3
63	S_EW DEPLOY	22844.7	0.0	22840.7	0.0	4.0
64	NB DEPLOY	22840.7	0.0	22840.7	0.0	0.0
65	DROP PL 2	22840.7	-5000.0	17840.7	0.0	0.0
66	THRUST FR PL 2	17840.7	0.0	17816.8	0.0	23.9
67	WB	17816.8	0.0	17816.7	0.0	0.1
68	S_EW IMU POI	17816.7	0.0	17815.1	0.0	1.7
69	NB IMU POI	17815.1	0.0	17815.0	0.0	0.1
70	POI	17815.0	0.0	17635.7	179.3	0.0
71	WB	17635.7	0.0	17603.9	0.0	31.8
72	S_EW MCC	17603.9	0.0	17603.0	0.0	0.8
73	NB MCC	17603.0	0.0	17603.0	0.0	0.0
74	MCC	17603.0	0.0	17602.3	0.0	0.7
75	WB	17602.3	0.0	17570.4	0.0	31.9
76	S_EW IMU MOI	17570.4	0.0	17568.7	0.0	1.7
77	NB IMU MOI	17568.7	0.0	17568.6	0.0	0.1
78	MOI	17568.6	0.0	17391.8	176.8	0.0
79	WB	17391.8	0.0	17389.8	0.0	2.0
80	S_EW TRACK	17389.8	0.0	17385.7	0.0	4.1
81	NB TRACK	17385.7	0.0	17384.2	0.0	1.4
82	TPI	17384.2	0.0	17336.3	47.9	0.0
83	S_EW TRACK	17336.3	0.0	17332.2	0.0	4.1
84	NB TRACK	17332.2	0.0	17330.8	0.0	1.4
85	MCC	17330.8	0.0	17330.6	0.0	0.2
86	S_EW TRACK	17330.6	0.0	17326.5	0.0	4.1
87	NB TRACK	17326.5	0.0	17325.0	0.0	1.4
88	TPF	17325.0	0.0	17244.0	0.0	81.0
89	S_EW DOCK	17244.0	0.0	17235.8	0.0	8.2
90	NB DOCK	17235.8	0.0	17235.5	0.0	0.3
91	DOCK PL 3	17235.5	0.0	17217.0	0.0	18.5
92	ADD PL 3	17217.0	5000.0	22217.0	0.0	0.0
93	WB	22217.0	0.0	22216.8	0.0	0.3
94	S_EW DEPLOY	22216.8	0.0	22212.9	0.0	3.9
95	NB DEPLOY	22212.9	0.0	22212.9	0.0	0.0
96	DROP PL 3	22212.9	-5000.0	17212.9	0.0	0.0
97	THRUST FR PL 3	17212.9	0.0	17189.8	0.0	23.0
98	WB	17189.8	0.0	17189.7	0.0	0.1
99	S_EW IMU POI	17189.7	0.0	17188.1	0.0	1.6
**	NB IMU POI	17188.1	0.0	17188.0	0.0	0.1
**	POI	17188.0	0.0	17102.9	85.1	0.0
**	WB	17102.9	0.0	17085.0	0.0	17.9
**	S_EW MCC	17085.0	0.0	17084.2	0.0	0.8
**	NB MCC	17084.2	0.0	17084.1	0.0	0.0
**	MCC	17084.1	0.0	17083.7	0.0	0.5
**	WB	17083.7	0.0	17065.7	0.0	17.9
**	S_EW IMU MOI	17065.7	0.0	17064.1	0.0	1.6
**	NB IMU MOI	17064.1	0.0	17064.0	0.0	0.1
**	MOI	17064.0	0.0	16979.5	84.5	0.0
**	WB	16979.5	0.0	16977.4	0.0	2.1
**	S_EW TRACK	16977.4	0.0	16973.4	0.0	4.0
**	NB TRACK	16973.4	0.0	16971.9	0.0	1.5
**	TPI	16971.9	0.0	16925.2	46.8	0.0
**	S_EW TRACK	16925.2	0.0	16921.1	0.0	4.0
**	NB TRACK	16921.1		16919.7	0.0	1.5
**	MCC	16919.7	0.0	16919.4	0.0	0.2
**	S_EW TRACK	16919.4	0.0	16915.4	0.0	4.0
**	NB TRACK	16915.4	0.0	16914.0	0.0	1.5
**	TPF	16914.0	0.0	16834.8	0.0	79.1
**	S_EW DOCK	16834.8	0.0	16826.9	0.0	8.0

** NB DOCK	16826.9	0.0	16826.6	0.0	0.3
** DOCK PL 4	16826.6	0.0	16808.5	0.0	18.0
** ADD PL 4	16808.5	5000.0	21808.5	0.0	0.0
** WB	21808.5	0.0	21808.3	0.0	0.3
** SLEW DEPLOY	21808.3	0.0	21804.5	0.0	3.8
** NB DEPLOY	21804.5	0.0	21804.4	0.0	0.0
** DROP PL 4	21804.4	-5000.0	16804.4	0.0	0.0
** THRUST FR PL 4	16804.4	0.0	16781.9	0.0	22.5
** WB	16781.9	0.0	16779.3	0.0	2.6
** SLEW IMU TOI	16779.3	0.0	16777.7	0.0	1.6
** NB IMU TOI	16777.7	0.0	16777.3	0.0	0.4
** TOI	16777.3	0.0	9775.5	7001.8	0.0
** FC REACT & MPS VENT	9775.5	0.0	9651.8	0.0	0.0
** WB	9651.8	0.0	9650.8	0.0	0.9
** SLEW MCC	9650.8	0.0	9650.4	0.0	0.5
** NB MCC	9650.4	0.0	9650.3	0.0	0.1
** MCC	9650.3	0.0	9628.3	0.0	22.0
** WB	9628.3	0.0	9627.4	0.0	0.9
** SLEW IMU POI	9627.4	0.0	9626.5	0.0	0.9
** NB IMU POI	9626.5	0.0	9626.0	0.0	0.5
** POI	9626.0	0.0	6818.5	2807.5	0.0
** FC REACT & MPS VENT	6818.5	0.0	6694.7	0.0	0.0
** WB	6694.7	0.0	6694.0	0.0	0.7
** SLEW MCC	6694.0	0.0	6693.7	0.0	0.3
** NB MCC	6693.7	0.0	6693.6	0.0	0.1
** MCC	6693.6	0.0	6683.7	0.0	9.9
** WB	6683.7	0.0	6683.0	0.0	0.7
** SLEW IMU CIRC	6683.0	0.0	6682.4	0.0	0.6
** NB IMU CIRC	6682.4	0.0	6681.6	0.0	0.7
** CIRC	6681.6	0.0	4468.1	2213.5	0.0
** WB	4468.1	0.0	4468.0	0.0	0.1
** SLEW ADJ	4468.0	0.0	4467.8	0.0	0.2
** NB ADJ	4467.8	0.0	4467.6	0.0	0.1
** ADJ	4467.6	0.0	4459.8	0.0	7.8
** WB	4459.8	0.0	4459.7	0.0	0.1
** SLEW EOS CAPTURE ST	4459.7	0.0	4459.5	0.0	0.2
** NB EOS CAPTURE ST	4459.5	0.0	4458.1	0.0	1.4
** CONTINGENCY 1.7(	4458.1	0.0	4268.1	190.0	0.0
				********	********
TOTALS				57938.0	1019.6

6.5.5 Ground/Onboard Autonomy Trade Study

The results of our autonomy trade study is presented in Figure 6.5.5-1 and concludes the following:

- Autonomy level IV is best suited to Option 1 concept 110A-1
- Autonomy level II is best suited for Options 2 and 3 where Option 3 starts with level III and evolves to level II.

The level I systems degraded performance resulting from the slow convergence characteristics of the Horizon Scanner/Star Tracker system makes this system unattractive. Our performance studies to date on this level I system have been preliminary in nature and we recommend that NASA and DOD initiate SR&T studies which combine a detail navigation analysis with a complete vehicle performance evaluation.

The level II system selected in our baselines requires the use of the 621B NAV SAT. This introduces significant schedule risk and technology issues. This NAV SAT system has sufficient coverage for spacecraft below 2000 N.M., introducing as a result the need for dedicated ground beacons (1-way doppler) for high altitude TUG operations. It is recommended that the interferometer approach which utilizes undedicated RF sources as landmarks be considered as an option.

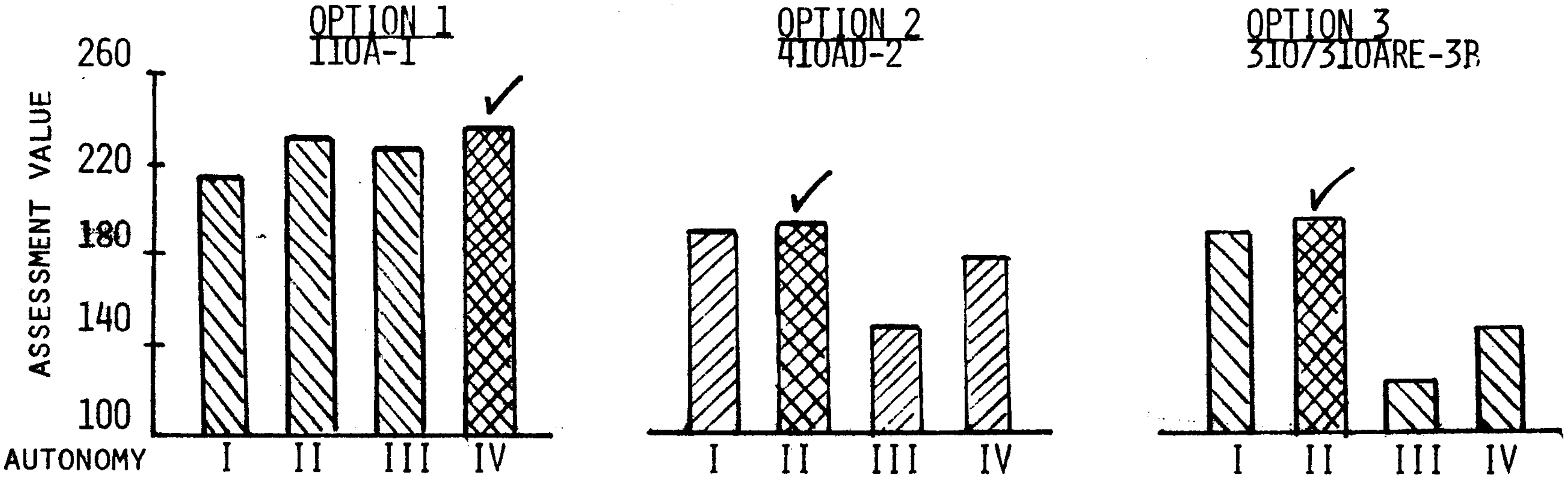
The level III system is a compromise approach. It introduces high development and operating cost for software for both the ground and on-board computer systems.

The level IV system is attractive for Option I due to low development costs. The high ground involvement and costs precludes the use of this approach for the more complex Option 2 and 3 programs.

Figure 6.5.5-2 summarizes the cost sensitivities for the three concepts evaluated. Figure 6.5.5-3 outlines the weights and performance. Figures 6.5.5-4 thru 6.5.5-5 lists the weights, DDT&E costs and production costs of the avionics systems used in the sensitivity evaluation.

FIG 6.5.5-1 AUTONOMY SENSITIVITY STUDY

- 0 LEVEL I — PERFORMANCE PENALTIES HIGHEST
- 0 LEVEL II — MOST ATTRACTIVE FOR OPTIONS 2 AND 3
  - RECOMMEND EVAL. OF INTERFEROMETER SYSTEM
- 0 LEVEL III — A COMPROMISE SYSTEM WITH HIGH COST GROUND & ONBOARD SOFTWARE
- 0 LEVEL IV — MOST ATTRACTIVE FOR LOW DDT & E OPTION 1



RANK	FACTORS	WT.
1	DDT & E	10
2	COST/FLT	8
3	COMPLEXITY	6
4	PERFORMANCE	5
5	TOTAL $	4
6	TECH. RISK	4
7	SCHED. RISK	3
8	SHUTTLE COMPT	1

GRUMMAN

Fig. 6.5.5-2 AUTONOMY SENSITIVITY STUDY

DELTA COSTS - $M

OPTION	1				2				3			
CONCEPT	110A-1				410AD-2				310/310ARE-3B			
AUTONOMY LEVEL	I	II	III*	IV	I	II*	III	IV	I	II*	III	IV
DDT & E												
o Avionics	3.0	1.5	-	-1.3	1.5	-	-1.5	-11.0	1.5	-	-1.5	-11.0
o Flt OPS	-3.1	-3.1	-	-3.1	-	-	+6.9	1.7	-	-	6.9	+ 1.7
SUB TOTAL	- .1	-2.6	-	-4.4	1.5	-	5.4	-9.3	1.5	-	5.4	-9.3
PRODUCTION												
o Avionics	5.0	1.6	-	-0.8	3.1	-	-3.5	-11.0	4.5		-5.1	-16.0
OPERATIONS												
o Flt OPS	-34.0	-34.0	-	9.5	-	-	45.0	58.0	-	-	65.2	87.6
TOTAL Δ PROGRAM	-29.1	-35.0	-	4.3	4.6	-	46.9	37.7	6.0	-	65.5	62.3

* BASELINE

Fig. 6.5.5-3 AUTONOMY SENSITIVITY STUDY-WEIGHT & PERFORMANCE

OPTION	1				2				3			
CONCEPT	110A-1				410AD-2				310/310ARE-3B			
AUTONOMY LEVEL	I	II	III*	IV	I	II*	III	IV	I	II*	III	IV
WEIGHTS (LBS)												
o Structure	1294	1294	1294	1294	1269	1269	1269	1269	1267	1267	1267	1267
o Thermal	77	77	77	77	69	69	69	69	69	69	69	69
o Astrionics	693	657	596	573	839	801	743	685	839	801	743	685
o Propulsion	734	734	734	734	737	737	737	737	738	738	738	738
DRY WT.	2798	2762	2701	2678	2914	2876	2818	2760	2913	2881	2817	2759
o Contingency	280	276	270	268	291	288	282	276	291	288	282	276
DRY WT. + CONT.	3078	3038	2971	2946	3205	3164	3100	3036	3204	3169	3099	3035
o Non-Usable	234	234	234	234	247	247	247	247	247	247	247	247
FIXED WEIGHT	3312	3272	3205	3180	3452	3411	3347	3283	3451	3416	3346	3282
Δ DELTA-V (fps)												
o Outbound	360	-30	0	0	390	0	30	30	390	0	30	30
o Inbound	105	0	0	0	105	0	0	0	105	0	0	0
PERFORMANCE												
o Deploy	2905	3805	4014	4111	4013	4914	5100	5466	3962	4841	5049	5292
o Retr'v.	-	-	-	-	1210	1574	1641	1780	1187	1543	1621	1709
o Rnd. Trip	-	-	-	-	821	1080	1132	1256	801	1054	1111	1175
o Deploy with AKS	7312	8099	8207	8265	5203	6021	6143	6409	-	-	-	-

* BASELINE

Fig. 6.5.5-4 AUTONOMY SENSITIVITY STUDY - ASTRIONICS LIST

OPTION 1 ; CONCEPT 110A-1 DATE 8/31/73

SUBSYSTEM o Component	AUTONOMY LEVEL I				AUTONOMY LEVEL II				AUTONOMY LEVEL III				AUTONOMY LEVEL IV			
	# UNITS	TOT'L WT(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)
GN&C																
o IMU	1	45	2.00	.532	1	45	2.00	.532	1	45	2.00	.532	1	45	2.00	.532
o Star Tracker	1	17	1.16	.245	1	17	1.16	.245	1	17	1.16	.245	1	17	1.16	.245
o APS Cont'l Elect.	2	36	3.40	.450	2	36	3.40	.450	2	36	3.40	.450	2	36	3.40	.450
o ME/TVC Cont'l Elect.	1	10	3.40	.450	1	10	3.40	.450	1	10	3.40	.450	1	10	3.40	.450
o Rate Gyro Assembly	1	5	0.40	.061	1	5	0.40	.061	1	5	0.40	.061	1	5	0.40	.061
o Horizon Tracker	1	425	1.72	.217												
o Satellite Rec'vr					1	37	1.00	.05								
o Doppler Rec'vr					1	8	)0.5	.03								
o L-Band Antenna					4	0.3	)									
o Combiner/Doppler Detect.					1	6	)									
		(156)	(12.08)	(1.955)		(164)	(11.86)	(1.818)		(113)	(10.36)	(1.738)		(113)	(10.36)	(1.738)
DMS																
o Computer	2	30	0.60	.500	2	30	0.60	.500	2	26	0.60	.500	2	22	0.60	.500
o Mass Memory	1	19	1.30	.070												
o Tape Recorder	1	14.5	1.30	.080	1	14.5	1.30	.080	1	14.5	1.30	.080				

Fig. 6.5.5-4 AUTONOMY SENSITIVITY STUDY - ASTRIONICS LIST (CONT.)

OPTION 1 ; CONCEPT 110A-1 DATE 8/31/73

SUBSYSTEM o Component	AUTONOMY LEVEL I				AUTONOMY LEVEL II				AUTONOMY LEVEL III				AUTONOMY LEVEL IV			
	# UNITS	TOT'L WT(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)
DMS (CONT)																
o FSI Controller/TLM Formater	1	18	2.8	.080	1	18	2.8	.080	1	18	2.8	.080	1	18	2.8	.080
o DACU's	4	28	1.2	.880	3	21	1.2	.660	3	21	1.2	.660	3	21	1.2	.660
o Sensors	200	40	0.6	.100	190	38	0.6	.100	180	36	0.6	.100	18	36	0.6	.100
		(149.5)	(7.8)	(1.71)		(121.5)	(6.5)	(1.42)		(115.5)	(6.5)	(1.42)		(97)	(5.2)	(1.34)
COMM																
o R'CUR (4) X'MTR (1)	1	5 16	0.8	.120	1	5 16	0.8	.120	1	5 16	0.8	.120	1	5 16	0.8	.120
o Aux X'MTR	1	5	0	.002	1	5	0	.002	1	5	0	.002	1	5	0	.002
o Power Ampl	2	2	0.15	.012	2	2	0.15	.012	2	2	0.15	.012	2	2	0.15	.012
o Diplexer	2	2	0.02	.002	2	2	0.02	.002	2	2	0.02	.002	2	2	0.02	.002
o Antenna Switch	1	1	0.03	.005	1	1	0.03	.005	1	1	0.03	.005	1	1	0.03	.005
o Base Band Processor	1	3	4.50	.190	1	3	4.50	.190	1	3	4.50	.190	1	3	4.50	.190
o OMNI Ant.	2	1	0.120	.006	2	1	0.120	.006	2	1	0.120	.006	2	1	0.120	.006
		(35)	(5.62)	(.34)		(35)	(5.62)	(.34)		(35)	(5.62)	(.34)		(35)	(5.62)	(.34)

Fig. 6.5.5-4 AUTONOMY SENSITIVITY STUDY - ASTRIONICS LIST (CONT.)

OPTION 1 ; CONCEPT 110A-1 DATE 8/31/73

SUBSYSTEM o Component	AUTONOMY LEVEL I				AUTONOMY LEVEL II				AUTONOMY LEVEL III				AUTONOMY LEVEL IV			
	# UNITS	TOT'L WT(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)
EPS																
o Primary Battery	1	201	1.36	.015	1	184	1.36	.015	1	180	1.36	.015	1	176	1.36	.015
o Emerg. Battery	1	10	0.35	.003	1	10	0.35	.003	1	10	0.35	.003	1	10	0.35	.003
o Vehicle Wiring		50)				50				50				50		
o Connectors		30)	1.06	.190		30	1.06	.190		30	1.06	.190		30	1.06	.190
o Saundries		16)				16				16				16		
o Solid State Power Cont'r		18	0.05	.009		18	0.05	.009		18	0.05	.009		18	0.05	.009
o Electro-Mech RCCB		6				6				6				6		
		(331)	(2.82)	(.217)		(314)	(2.82)	(.217)		(310)	(2.82)	(.217)		(306)	(2.82)	(.217)
TOTAL WT.		(653)				(616.8)				(556)				(533)		
TOTAL DDT&E			(28.3)				(26.8)				(25.3)				(24.0)	
Fleet Size = 11 Total Production				(42.2)				(38.8)				(37.2)				(36.4)

Fig. 6.5.5-5 AUTONOMY SENSITIVITY STUDY - ASTRIONICS LIST

OPTION 2 ; CONCEPT 410 AD-1 DATE 8/31/73

SUBSYSTEM	AUTONOMY LEVEL I				AUTONOMY LEVEL II				AUTONOMY LEVEL III				AUTONOMY LEVEL IV			
o Component	# UNITS	TOT'L WT(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)
GN&C																
o IMU (Micron)	2	20	6.60	.600	2	20	6.60	.600	2	20	6.60	.600	2	20	6.60	.600
o Star Tracker	2	34	1.16	.480	2	34	1.16	.480	1	17	1.16	.240	1	17	1.16	.240
o APS Cont'l Elect.	2	36	3.40	.880	2	36	3.40	.880	2	36	3.40	.880	2	36	3.40	.880
o ME/TVC Cont'l Elect.	1	10	3.40	.440	1	10	3.40	.440	1	10	3.40	.440	1	10	3.40	.440
o Horizon Tracker	1	42.5	1.72	.217												
o Satellite Receiver					1	37	1.00	.05								
o Doppler Receiver					1	8	0.50	.03								
o L-Band Antenna					4	1.2										
o Combiner/Doppler Detect.					1	6										
o Laser Radar	1	40	8.20	.600	1	40	8.20	.600	1	40	8.20	.600				
		(182.5)	(24.48)	(3.22)		(192.2)	(24.26)	(3.08)		(123)	(22.76)	(2.76)		(83.0)	(14.56)	(2.16)
DMS																
o Computer	2	30	0.6	.600	2	30	0.6	.600	2	26	0.6	.600	2	22	0.6	.600
o Mass Memory	2	38	1.3	.140												
o Tape Recorder	1	14.5	1.3	.08	1	14.5	1.3	.08								
o FSI Controller/ TLM Formater	1	18	2.8	.08	1	18	2.8	.08	1	14.5	1.3	.08				
o Dacus	4	28	1.2	.88	3	21	1.2	.88	3	21	1.2	.88	3	21	1.2	.88
o Sensors		40	0.6	.105		38	0.6	.105		36	0.6	.105		36	0.6	.105
		(168.5)	(7.8)	(1.89)		(121.5)	(6.5)	(1.75)		(115.5)	(6.5)	(1.75)		(97)	(52)	(1.67)

Fig. 6.5.5-5 AUTONOMY SENSITIVITY STUDY - ASTRIONICS LIST (CONT.)

OPTION 2 ; CONCEPT 410ADE-2 DATE 8/31/73

SUBSYSTEM o Component	AUTONOMY LEVEL I				AUTONOMY LEVEL II				AUTONOMY LEVEL III				AUTONOMY LEVEL IV			
	# UNITS	TOT'L WT(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)
COMM																
o R'cvr	1	8	1.29	.11	1	8	1.29	.11	1	8	1.29	.11	1	8	1.29	.11
o X'mtr	1	5			1	5			1	5			1	5		
o R'cvr	1	16	.81	.12	1	16	.81	.12	1	16	.81	.12	1	16	.81	.12
o X'mtr	1	5			1	5			1	5			1	5		
o Aux' X'mtr	1	5	-	.001	1	5	-	.001	1	5	-	.001	1	5	-	.001
o Power Amp 1	1	1	.150	.005	1	1	.150	.005	1	1	.150	.005	1	1	.150	.005
o Power Amp 2	1	3	-	.005	1	3	-	.005	1	3	-	.005	1	3	-	.005
o Baseband Processor	1	6	4.5	.182	1	6	4.5	.182	1	6	4.5	.182	1	6	4.5	.182
o Diplexer 1	2	2	.02	.002	2	2	.02	.002	2	2	.02	.002	2	2	.02	.002
o Diplexer 2	2	2	.02	.002	2	2	.02	.002	2	2	.02	.002	2	2	.02	.002
o Antenna Switch 1	2	2	.03	.010	2	2	.03	.010	2	2	.03	.010	2	2	.03	.010
o Antenna Switch 2	2	2	-	.010	2	2	-	.010	2	2	-	.010	2	2	-	.010
o Antenna	2	1	.12	.004	2	1	.12	.004	2	1	.12	.004	2	1	.12	.004
o Antenna	2	1	-	.004	2	1	-	.004	2	1	-	.004	2	1	-	.004
o Power Splitter	1	1	.02	.002	1	1	.02	.002	1	1	.02	.002	1	1	.02	.002
o TV Assembly	1	12	1.05	.150	1	12	1.05	.150	1	12	1.05	.150	1	12	1.05	.150
		(72)	(8.01)	(.607)		(72)	(8.01)	(.607)		(72)	(8.01)	(.607)		(72)	(8.01)	(.607)

Fig. 6.5.5-5 AUTONOMY SENSITIVITY STUDY - ASTRIONICS LIST (CONT.)

OPTION 2 ; CONCEPT 410 AD-1 DATE 8/31/73

SUBSYSTEM o Component	AUTONOMY LEVEL I				AUTONOMY LEVEL II				AUTONOMY LEVEL III				AUTONOMY LEVEL IV			
	# UNITS	TOT'L WT(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)
EPS																
o Modified Fuel Cell	1	90	3.50	.147	1	90	3.50	.147	1	90	3.50	.147	1	90	3.50	.147
o Emergency Battery	1	15	0.35	.003	1	15	0.35	.003	1	15	0.35	.003		15	0.35	.003
o Re'Actant Storage									1	66			1	66		
o Cryo Hydrogen Tank Assy.	1	66	11.5	.314	1	66	11.5	.314			11.5	.314			11.5	.314
o Cryo Ox Tank Assy	1	68			1	68			1	68			1	68		
o Vehicle Wiring		55				55				55				55		
o Connectors		30	1.140	.202		30	1.140	.202		30	1.140	.202		30	1.140	.202
o Sundries		20				20				20				20		
o Solid State Pwr. Control		21	.50	.01		21	.50	.01		21	.50	.01		21	.50	.01
o Electro-Mech RccB		9				9				9				9		
		(374)	(16.99)	(.676)		(374)	(16.99)	(.676)		(374)	(16.99)	(.676)		(374)	(16.99)	(.676)
TOTAL		(797)				(759)				(684)				(626)		
TOTAL DDT&E			(57.28)				(55.76)				(54.26)				(44.76)	
FLEET SIZE = 11 PRODUCTION $				(70.29)				(67.21)				(63.69)				(56.21)

Fig. 6.5.5-6 AUTONOMY SENSITIVITY STUDY - ASTRIONICS LIST

OPTION 3 ; CONCEPT 310 ARE-1 DATE 8/31/73

SUBSYSTEM o Component	AUTONOMY LEVEL I				AUTONOMY LEVEL II				AUTONOMY LEVEL III				AUTONOMY LEVEL IV			
	# UNITS	TOT'L WT(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)
GN&C																
o IMU	2	20	6.60	.600	2	20	6.60	.600	2	20	6.60	.600	2	20	6.60	.600
o Star Tracker	2	34	1.16	.480	2	34	1.16	.480	2	34	1.16	.480	2	34	1.16	.480
o APS Cont'l Elect.	2	36	3.40	.880	2	36	3.40	.880	2	36	3.40	.880	2	36	3.40	.880
o ME/TVC Cont'l Elect.	1	10	3.40	.440	1	10	3.40	.440	1	10	3.40	.440	1	10	3.40	.440
o Horizon Tracker	1	42.5	1.72	.217												
o Satellite Rec'vr					1	37	1.00	.05								
o Doppler Rec'vr					1	8	.50	.03								
o L-Band Antenna					4	1.2										
o Combiner/Doppler Detect.					1	6										
o Laser Radar	1	40	8.20	.600	1	40	8.20	.600	1	40	8.20	.600				
		(182.5)	(24.18)	(3.22)		(192.2)	(24.26)	(3.08)		(123)	(22.76)	(3.00)		(83.0)	(14.56)	(2.40)
DMS																
o Computer	2	30	.6	.600	2	30	.6	.600	2	26	.6	.600	2	22	.6	.600
o Mass Memory	2	38	1.3	.140												
o Tape Recorder	1	14.5	1.3	.080	1	14.5	1.3	.080	1	14.5	1.3	.080				
o FSI Controller/ TLM Formater	1	18	2.8	.080	1	18	2.8	.080	1	18	2.8	.080	1	18	2.8	.080
o Dacus	4	28	1.2	.880	3	21	1.2	.880	3	21	1.2	.880	3	21	1.2	.880
o Sensors		40	.6	.105		38	.6	.105		36	.6	.105		36	.6	.105
		(168.5)	(7.8)	(1.89)		(121.5)	(6.5)	(1.75)		(115.5)	(6.5)	(1.75)		(97)	(5.2)	(1.67)

Fig. 6.5.5-6 AUTONOMY SENSITIVITY STUDY - ASTRIONICS LIST (CONT.)

OPTION 3 ; CONCEPT 310 ARE-1 DATE 8/31/73

SUBSYSTEM o Component	AUTONOMY LEVEL I				AUTONOMY LEVEL II				AUTONOMY LEVEL III				AUTONOMY LEVEL IV			
	# UNITS	TOT'L WT(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)
COMM																
o R'cvr	1	8	1.29	.11	1	8	1.29	.11	1	8	1.29	.11	1	8	1.29	.11
o X'mtr	1	5			1	5			1	5			1	5		
o R'cvr	1	16	.81	.12	1	16	.81	.12	1	16	.81	.12	1	16	.81	.12
o X'mtr	1	5			1	5			1	5			1	5		
o Aux' X'mtr	1	5	-	.001	1	5	-	.001	1	5	-	.001	1	5	-	.001
o Power Amp 1	1	1	.150	.005	1	1	.150	.005	1	1	.150	.005	1	1	.150	.005
o Power Amp 2	1	3	-	.005	1	3	-	.005	1	3	-	.005	1	3	-	.005
o Baseband Processor	1	6	4.5	.182	1	6	4.5	.182	1	6	4.5	.182	1	6	4.5	.182
o Diplexer 1	2	2	.02	.002	2	2	.02	.002	2	2	.02	.002	2	2	.02	.002
o Diplexer 2	2	2	.02	.002	2	2	.02	.002	2	2	.02	.002	2	2	.02	.002
o Antenna Switch 1	2	2	.03	.010	2	2	.03	.010	2	2	.03	.010	2	2	.03	.010
o Antenna Switch 2	2	2	-	.010	2	2	-	.010	2	2	-	.010	2	2	-	.010
o Antenna	2	1	.12	.004	2	1	.12	.004	2	1	.12	.004	2	1	.12	.004
o Antenna	2	1	-	.004	2	1	-	.004	2	1	-	.004	2	1	-	.004
o Power Splitter	1	1	.02	.002	1	1	.02	.002	1	1	.02	.002	1	1	.02	.002
o TV Assembly	1	12	1.05	.150	1	12	1.05	.150	1	12	1.05	.150	1	12	1.05	.150
		(72)	(8.01)	(.607)		(72)	(8.01)	(.607)		(72)	(8.01)	(.607)		(72)	(8.01)	(.607)

Fig. 6.5.5-6 AUTONOMY SENSITIVITY STUDY - ASTRIONICS LIST (CONT.)

OPTION 3 ; CONCEPT 310 ARE-1 DATE 8/31/73

SUBSYSTEM o Component	AUTONOMY LEVEL I				AUTONOMY LEVEL II				AUTONOMY LEVEL III				AUTONOMY LEVEL IV			
	# UNITS	TOT'L WT(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD ($M)	# UNITS	TOT'L WT.(LBS)	DDT&E ($M)	PROD. ($M)
EPS																
o Modified Fuel Cell	1	90	3.50	.147	1	90	3.50	.147	1	90	3.50	.147	1	90	3.50	.147
o Emergency Battery	1	15	.35	.003	1	15	.35	.003	1	15	.35	.003	1	15	.35	.003
o Re'Actant Storage																
- Cryo Hydrogen Tank Assy	1	69	11.5	.314	1	69	11.5	.314	1	69	11.5	.314	1	69	11.5	.314
- Cryo Ox Tank Assy.	1	71			1	71			1	71			1	71		
o Vehicle Wiring		55				55				55				55		
o Connectors		30	1.14	.202		30	1.14	.202		30	1.14	.202		30	1.14	.202
o Sundries		20				20				20				20		
o Solid State Pwr. Contr.		21	.50	.01		21	.50	.01		21	.50	.01		21	.50	.01
o Electro-Mech. RccB		9				9				9				9		
		(380)	(16.99)	(.676)		(380)	(16.99)	(.676)		(380)	(16.99)	(.676)		(380)	(16.99)	(.676)
TOTAL		(803.)				(765)				(690)				(632)		
TOTAL DDT&E			(57.28)				(55.76)				(54.26)				(44.76)	
FLEET SIZE = 46																
PRODUCTION $				(102.24)				(97.76)				(92.64)				(81.76)

6.5.6 On-Board/Orbiter/Ground Checkout Tradeoff

The method of performing on orbit Tug checkout and malfunction detection and corrective actions is dependent on time criticality and crew safety considerations. A time critical function such as monitoring for rough combustion, rapidly rising tank pressure or failure of a cryo tank to vent will always be monitored and corrective action taken by the Tug Data Management System. A failure on board the tug which could jeopardize the safety of the orbiter crew such as an attitude hold or APS system failure with the possibility of Tug/Orbiter collision will be corrected by the Tug Data Management System to the extent possible with command override capability from the Orbiter Mission Specialist Station. Non time critical functions which do not have a Crew Safety impact will be implemented in accordance with the level of autonomy to which the Tug/Orbiter is designed. The description of the Ground/On-Board autonomy tradeoff in para 6.5.5 is a description of present thinking on the question of checkout allocation.

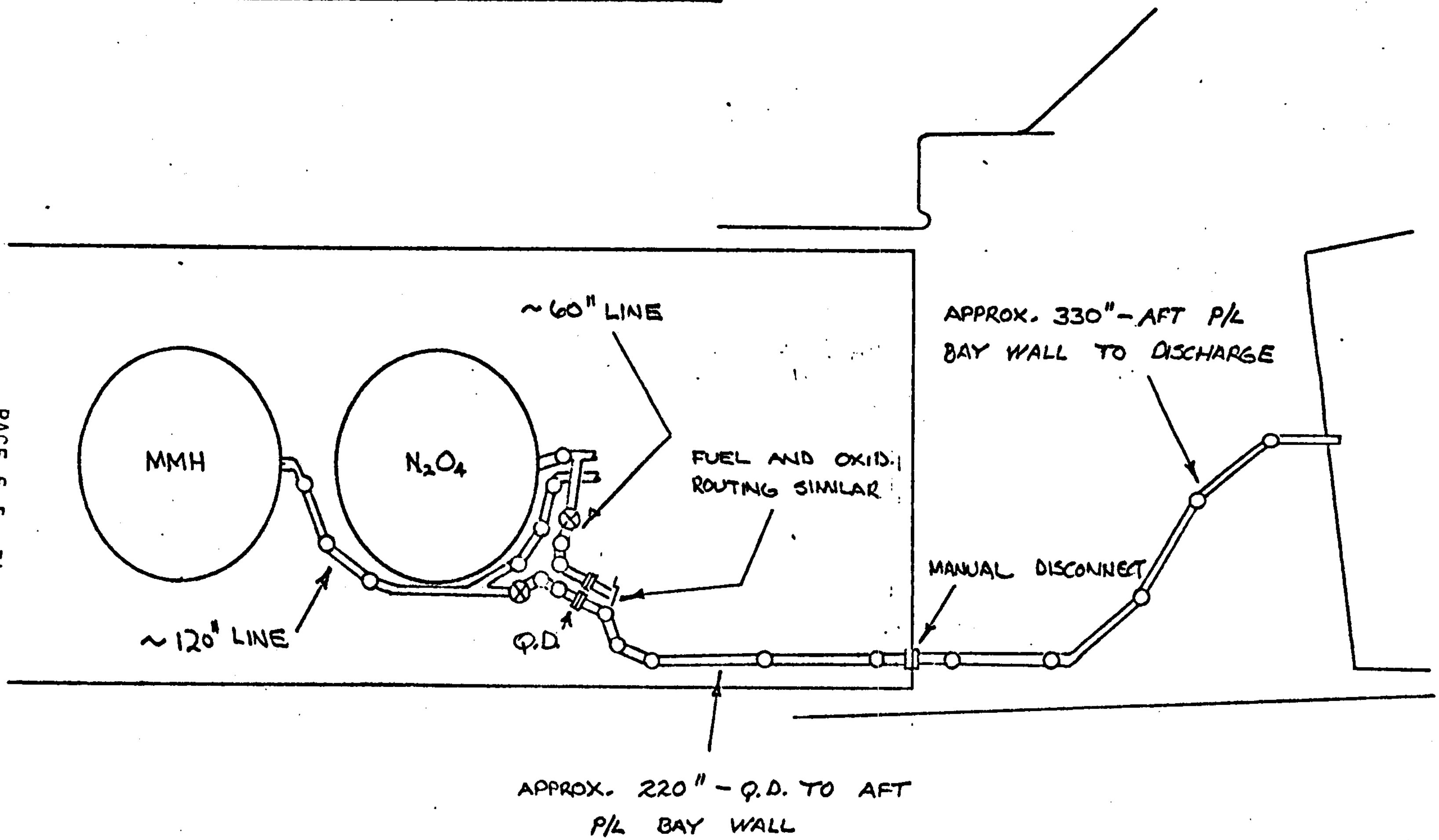
Upon completion of subsystem definition, a detailed analysis to determine the specific parameters to be monitored, diagnostic and corrective techniques time and ground coverage available and their impact on mission tug and support hardware will be initiated. The specific method of checkout selected is strongly hardware dependent and must be maintained flexible until reasonable design maturity is achieved and reliability estimates factored into the analysis.

6.5.7 IN-FLIGHT DUMP SENSITIVITY

- DESIGN DUMP SYSTEM FOR MODE III ABORT
- DESIGN FOR DUMP DURING SHUTTLE POWERED FLIGHT ONLY, TO AVOID SIDE TANK OUTLETS AND TAKE ADVANTAGE OF HIGH G LEVEL
- MINIMUM OF 300 SEC. AVAILABLE, DESIGN TO DUMP ENTIRE LOAD IN THIS TIME
- ENLARGE FEED LINES AND GROUND VERTICAL DRAIN LINES TO ACCOMMODATE INCREASED FLOW RATE
- FOR SIMPLICITY, ALL LINES ASSUMED TO HAVE THE SAME DIAMETER
- STUDY CONDUCTED FOR 110A-1, VERY SIMILAR RESULTS EXPECTED FOR OTHER CONFIGURATIONS

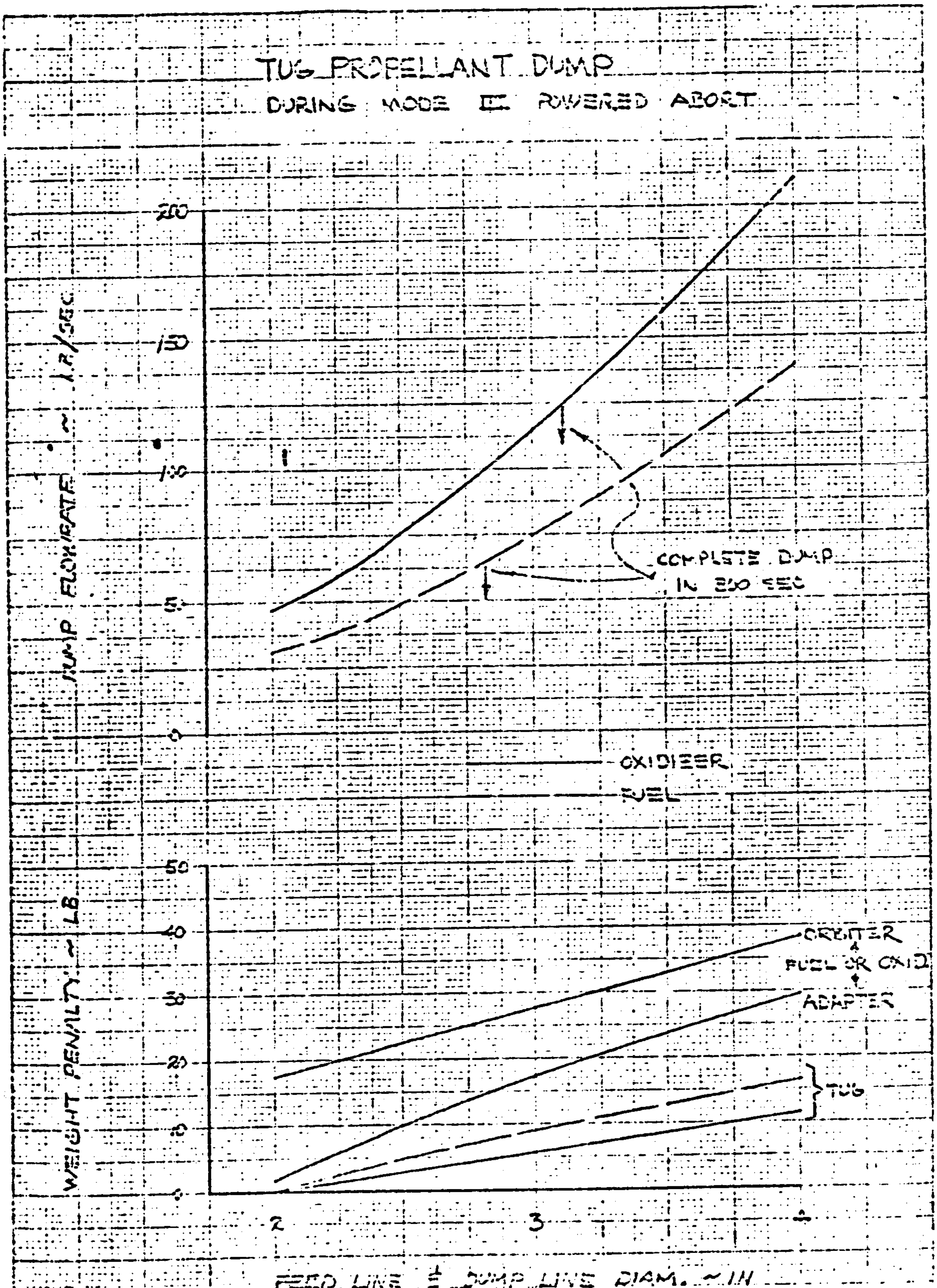
GRUMMAN

IN-FLIGHT DUMP SCHEME



NOTE : 1) ALL FLUID LINES ASSUMED SAME DIAMETER

2) Q.D.'s REPLACED BY LOW RESISTANCE DESIGNS


TUG PROPELLANT DUMP
DURING MODE III POWERED ABORT
DUMP FLOWRATE ~ LB/SEC
200
150
100
50
0
COMPLETE DUMP IN 200 SEC
OXIDIZER
FUEL
WEIGHT PENALTY ~ LB
50
40
30
20
10
0
ORBITER
FUEL OR OXID
ADAPTER
TUG
2
3
4
FEED LINE & DUMP LINE DIAM. ~ IN

IN-FLIGHT DUMP SENSITIVITY

CHANGES TO BASELINE SYSTEM

- FEEDLINE, FILL/DRAIN, ADAPTER, AND SHUTTLE SERVICE LINES INCREASED TO 3.25 IN DIAMETER
- FILL/DRAIN Q.D.'S MUST BE ALL NEW LOW RESISTANCE DESIGN, PRESENT (LM/SPS) DESIGNS HAVE HIGH PRESSURE DROP DUE TO POPPET ARRANGEMENT

FEED SYSTEM WEIGHT PENALTIES

TUG	18 LB. INCREASE
ADAPTER	41 LB. INCREASE
SHUTTLE	60 LB. (TOTAL WEIGHT, PRESENT SYSTEM UNKNOWN)

GRUMMAN

ON-ORBIT DUMP

- o IF SYSTEM IS DESIGNED FOR MODE III ABORT CAN PROPELLANT BE DUMPED ON A ONCE-AROUND ABORT?

- o YES

  - DUMP TIME INCREASED TO 10 MINUTES
  - 5% RESIDUAL WILL REMAIN IN TANKS
  - REQUIRES ONE SHUTTLE RCS ENGINE TO BURN FOR THE 10 MINUTE DUMP (PLUS A 14% DUTY CYCLE ON A NOSE JET TO YAW COMPENSATE)
  - CONSUMES 2000 LB. SHUTTLE RCS PROPELLANT AND 50% DEPLETES ONE AFT RCS MODULE

GRUMMAN

VEHICLE WEIGHT SAVINGS

- LANDING WITHOUT PROPELLANT LOAD CAN SAVE TANKAGE AND STRUCTURAL WEIGHT
- ABORT LANDING IS THE CRITICAL DESIGN CONDITION WITH FULL PROPELLANT
- STRUCTURAL WEIGHTS ASSOCIATED WITH THE SENSITIVITY ARE MAIN PROPULSION TANKS, TUG FORWARD SUPPORT FRAME AND TUG/SHUTTLE INTERFACE FORWARD FRAME

GRUMMAN

STRUCTURAL WEIGHT SAVINGS (LB. DECREASE)

TO LAND WITHOUT PROPELLANT

CONFIGURATION / ITEM	NESTED DOME		SEPARATE TANKS
	(510) ALUMINUM TANKS	(310,410) TITANIUM TANKS	(110) ALUMINUM TANKS
MAIN PROPULSION TANKS	12	5	18
FWD SUPPORT FRAME	39	39	38
TOTAL TUG	51	44	56
ADAPTER	199	199	199

NOTE: DOES NOT INCLUDE CONTINGENCY

GRUMMAN

IN-FLIGHT PROPELLANT DUMP

SAFETY ISSUE

- DUMP SYSTEM IS NOT REDUNDANT. CAN WE LAND SAFELY IF IT FAILS?
- TWO FAILURES REQUIRED TO NOT DUMP ALL PROPELLANTS, THREE TO NOT DUMP ANY
- SAFE LANDING IS STILL POSSIBLE WITH FULL TANKS IF OVERLOAD SINKING SPEED IS USED
- WEIGHT PENALTY TO PROVIDE REDUNDANCY IS APPROXIMATELY 25 LB. ON TUG AND 10 LB. ON ADAPTER

GRUMMAN

IN-FLIGHT DUMP

WEIGHT SUMMARY (LB. INCREASE)

(110A-1 VEHICLE)

	TUG	ADAPTER	SHUTTLE
FLUID SYSTEMS	+18	+41	+60
STRUCTURE	-56	-199	0
SUBTOTAL	-38	-158	+60
10% CONTINGENCY	- 4	- 16	+ 6
TOTAL	-42	-174	+66
EQUIVALENT TUG WT.*	-42	- 11	+ 4

TOTAL EQUIVALENT
TUG INERT WEIGHT CHANGE - 49 LB.

* USING A 16:1 RATIO FOR ADAPTER AND SHUTTLE EQUIPMENT

GRUMMAN

IN-FLIGHT DUMP

COST ANALYSIS

	FLUID COMPONENTS	STRUCTURAL COMPONENTS
Δ DDT&E ($1000)	+300	-700
Δ RECURRING ($1000)	+560	-525
TOTAL	+860	-1225

NET COST SAVINGS = $365,000

GRUMMAN

TUG MISSION TIMELINE

TABLE 6.6-1 TUG CHECKOUT PROCEDURES (Sheet 1 of 8) DATE

G.E.T. HR:MIN:SEC:	ΔT HR:MIN:SEC:	EVENT OPERATION	REMARKS
	TBD	<u>ORBITER OPERATIONS</u>	
		Release Cargo Bay Door Locks	
		Open Orbiter Cargo Bay Doors	
		Activate and Checkout Mission Specialist Station	
		Activate and Checkout Payload Specialist Station	
		Activate and Checkout Docking & Manipulator Handing Station	
		Checkout lighting	
		Checkout TV	
		Checkout Controls & Displays	
		Verify Electrical Power to Tug and Payload	
		Monitor voltage & current levels	o Power for Tug supplied by orbiter o Power for Payload supplied by orbiter via tug

*GAC 3994 8-73

TUG MISSION TIMELINE

TABLE 6.6-1 TUG CHECKOUT PROCEDURES (Sheet 2 of 8) DATE

G.E.T. HR:MIN:SEC:	ΔT HR:MIN:SEC:	EVENT OPERATION	REMARKS
		Monitor Tug and Payload Critical Parameters (Orbiter Caution and Warning Display)	o Parameters hardlined to orbitor
		Release Manipulator Latches	o Payload bay parameters o MPS He Tank Press o MPS Fuel Tank Press. o MPS Oxid Tank Press. o APS He Tank Press. o APS Prop Tank Press. o EPS H_2 (Cryo) Press. o EPS O_2 (Cryo) Press.
		Deploy Manipulator	
		Checkout Manipulator	
		Activate and Checkout Translation, Rotation position and Rates.	
		Connect Manipulator to Tug	
		Verify mechanical interface between manipulator and Tug	o Assume status of latches is hardlined to orbiter
		Verify mechanical interface between Tug and Payload	

TUG MISSION TIMELINE

TABLE 6.6-1 TUG CHECKOUT PROCEDURES (Sheet 3 of 8) DATE

G.E.T. HR:MIN:SEC:	ΔT HR:MIN:SEC:	EVENT OPERATION	REMARKS
		Monitor Tug and Payload critical parameters	
	00:30:00	TUG CHECKOUT	
		Activate Tug	
		Obtain ground verification that tug is ready for activation	
		Initiate Checkout Data Management System DMS provides GO to continue checkout Configure Tug for checkout Verify EPS Fuel Cells are off-line	o Assume orbiter can act as a comm relay link for tug while hardlined
		Initiate activation of EPS Fuel Cells DMS verify that Fuel Cells are venting DMS provide GO to activate GN & C DMS activate GN & C and initialize DMS activate backup guidance system DMS activate comm system	o Ground station and/or Mission Specialist will monitor Tug status and reconfigure via command override where necessary. o Allow warm up of 30 min o Allow warmup of 15 min o Allow warmup of 15 min

5-

TUG MISSION TIMELINE

TABLE 6.6-1 TUG CHECKOUT PROCEDURES (Sheet 4 of 8) DATE

G.E.T. HR:MIN:SEC:	ΔT HR:MIN:SEC:	EVENT OPERATION	REMARKS
		Verify Adaptor ready for extention	
		DMS provide Go to extend Tug	
		Initiate Extention of Tug	
		Release Tug and Payload to Orbiter Fwd Frame latches	
		Release venting lines	
		Prepare to extend Tug/Payload	
	00:10:00	<u>EXTEND TUG/PAYLOAD</u>	
		Orbiter extend Tug/Payload	
		<u>TUG CHECKOUT WHILE EXTENDED</u>	
		Verify Tug to Orbiter Comm	
		Verify Tug to payload Comm (GND & Orbiter Link)	
		Initiate APS Activation	
		Monitor APS parameters	
		DMS activate radar	
		DMS initiate radar self-check	
		DMS initiate backup guidance self-check	
		DMS provide Go for alignment	
		Initiate Data Transfer for initial alignment	o Utilizing orbiter computer bit stream

*GAC 3994 6-73

TUG MISSION TIMELINE

TABLE 6.6-1 TUG CHECKOUT PROCEDURES (Sheet 5 of 8)

DATE

G.E.T. HR:MIN:SEC:	ΔT HR:MIN:SEC:	EVENT OPERATION	REMARKS
		Monitor backup guidance	
		Transfer state vector data from ground via orbiter computer	
		Initiate APS cold fire check	
		Monitor APS	
		Monitor EPS parameters	
		Configure EPS for switchover to Tug Power	
		DMS provide Go for switchover	
		Initiate switchover to Tug power	
		Monitor EPS parameters	
		Remove Orbiter to Tug EPS	
		Monitor Tug critical parameters	
		DMS configure GN & C for release	
		Monitor GN&C configured for release	
		Receive DMS Go to release Tug	
	00:10:00	<u>TUG DEPLOYMENT</u>	
		Separate Tug/Payload from Adapter with Manipulator and position it for release	
		Release Tug	
	00:30:00	<u>TUG CHECKOUT WHILE SEPARATED</u>	
		Enable Tug attitude control jets	
		Tug maintains attitude	
		Perform visual inspection (moving orbiter or by slow rotation of Tug)	o Do not translate Tug
		Verify Tug/Orbiter and Tug/ground comm.	
		Check out TV by pointing it at orbiter and verify good reception	
		DMS position, Tug for fine alignment, fine align guidance system	
		Establish safe loiter distance	
		Initiate pressurization of MPS	
		DMS verify MPS pressurized	
		Perform MPS gimbal drive check	
		DMS provide gimbal drive GO indication	

TUG MISSION TIMELINE

TABLE 6.6-1 TUG CHECKOUT PROCEDURES (Sheet 6 of 8) DATE

G.E.T. HR:MIN:SEC:	ΔT HR:MIN:SEC:	EVENT OPERATION	REMARKS
		MSS operator commands rotation in 3 axes DMS verifies rotation override capability MSS operator commands translation in 3 axes DMS verifies translation override capability DMS verifies GN&C fine align DMS verifies of backup guidance DMS enable MPS DMS align gimbal for Phasing orbit insertion DMS monitor Tug Systems and provide Go for Phasing Orbit Insertion	
	TBD	ORBITER	
		Retract Manipulator	
		Deactivate Docking and Manipulator Handling Station	

*GAC 3994 6-73

TUG MISSION TIMELINE

TABLE 6.6-1 TUG CHECKOUT PROCEDURES (Sheet 7 of 8)

DATE

G.E.T. HR:MIN:SEC:	ΔT HR:MIN:SEC:	EVENT OPERATION	REMARKS
		ORBITER/TUG DOCKING	
		Orbiter Terminal Phase Initiation	
		Midcourse Correction if Required	
		Orbiter Perform braking gates/station keep with Tug	
		Prepare Tug/Payload for docking	
		DMS initiate venting of MPS tanks	
		DMS verify tanks vented to 20 psia	
		DMS initiate venting Tug Cryo tanks	
		DMS verify tanks vented to 20 psia	
		MSS operator confirms ability to override Tug translation & rotation commands	o Assume no requirement to vent APS tanks
		DMS select narrow D.B. for capture	
		Verify Tug/Payload GO for capture	
		Tug Capture	
		Release Manipulator Arm latches	
		Deploy manipulator arm	
		Checkout manipulator	
		Verify adaptor ready to receive Tug	
		Capture Tug	
	00:20:00	**DOCK ORBITER TO TUG**	
		Verify mechanical interface between manipulator and Tug	
		Vent APS tanks to 20 psia	
		Mate Tug with rear adaptor	
		Hard Dock	
		Verify Tug/Orbiter electrical interfaces	

*GAC 3994 6-73

TABLE 6.6-1 TUG CHECKOUT PROCEDURES (Sheet 8 of 8) DATE

G.E.T. HR:MIN:SEC:	ΔT HR:MIN:SEC:	EVENT OPERATION	REMARKS
		Deactivate Tug subsystems	
		Verify Orbiter/Tug electrical power	
		Shut down Tug fuel cells	
		Verify Tug/Payload ready for stowage	
	00:15:00	<u>STOW TUG/PAYLOAD IN ORBITER CARGO BAY</u>	
		Reconnect venting connectors	
		Verify connections	
		Retract Tug into payload bay	
		Connect fwd. frame	
		<u>STOW MANIPULATOR</u>	

6.8 Guidance Update Analysis

This discussion defines the quality of the navigation system (i.e., IMU and redundant sensors) in terms of commensurate ΔV penalty using post - MOI payload deployment specs as the lower requirement.

6.8.1 RESULTS OF SPACE TUG NAVIGATION SYSTEM PERFORMANCE REQUIREMENTS ANALYSIS FOR THE GEOSYNCHRONOUS PAYLOAD DEPLOYMENT MISSION

SUMMARY

The results of a simplified analysis of the Tug navigation system requirements based on satisfying the Tug Data Package payload deployment accuracy are contained herein. For the purposes of this analysis, the earliest payload deployment point was used; immediately after the Mission Orbit Insertion (MOI), burn at synchronous altitude. Under the assumption that a perfect midcourse correction maneuver is executed somewhere between the 1/4 and 3/4 time point of the 18,565 second transfer orbit, the navigation update prior to this midcourse has a maximum allowable error in the range of:

- 3 to 5 FPS RSS 1 sigma in velocity
- 40,000 to 50,000 Ft. RSS 1 sigma in position

The "IMU system", which is defined loosely as that portion of the astrionics determining attitude alignment and drift plus closed-loop velocity sensing accuracies, was given a budget of 13 FPS total velocity error for the MOI burn. The 13 FPS total velocity error is consistent with:

- 1 mrad/axis attitude bias error
- 200 μg/axis accelerometer bias error

It is noted that the synchronous altitude payload deployment components of crossrange position error and downrange velocity error are the driver elements in determining the navigation update and IMU system requirements. Any future change in either of these specifications should be immediately factored into navigation system requirements.

INTRODUCTION

The outbound leg of the geosynchronous Tug mission contains three main engine burns; one for Phasing Orbit Insertion (POI), one for Transfer Orbit Insertion (TOI), and one for Mission Orbit Insertion (MOI). Preliminary sensitivity studies have shown that completely impractical initial condition error tolerances and unrealistic IMU systems would be required if a midcourse correction is not postulated between TOI and MOI. Even with perfect position and velocity information at the start of the TOI burn, state-of-the-art IMU systems cannot approach the post-MOI payload deployment accuracy requirements without providing for a midcourse correction preceded by a navigation update.

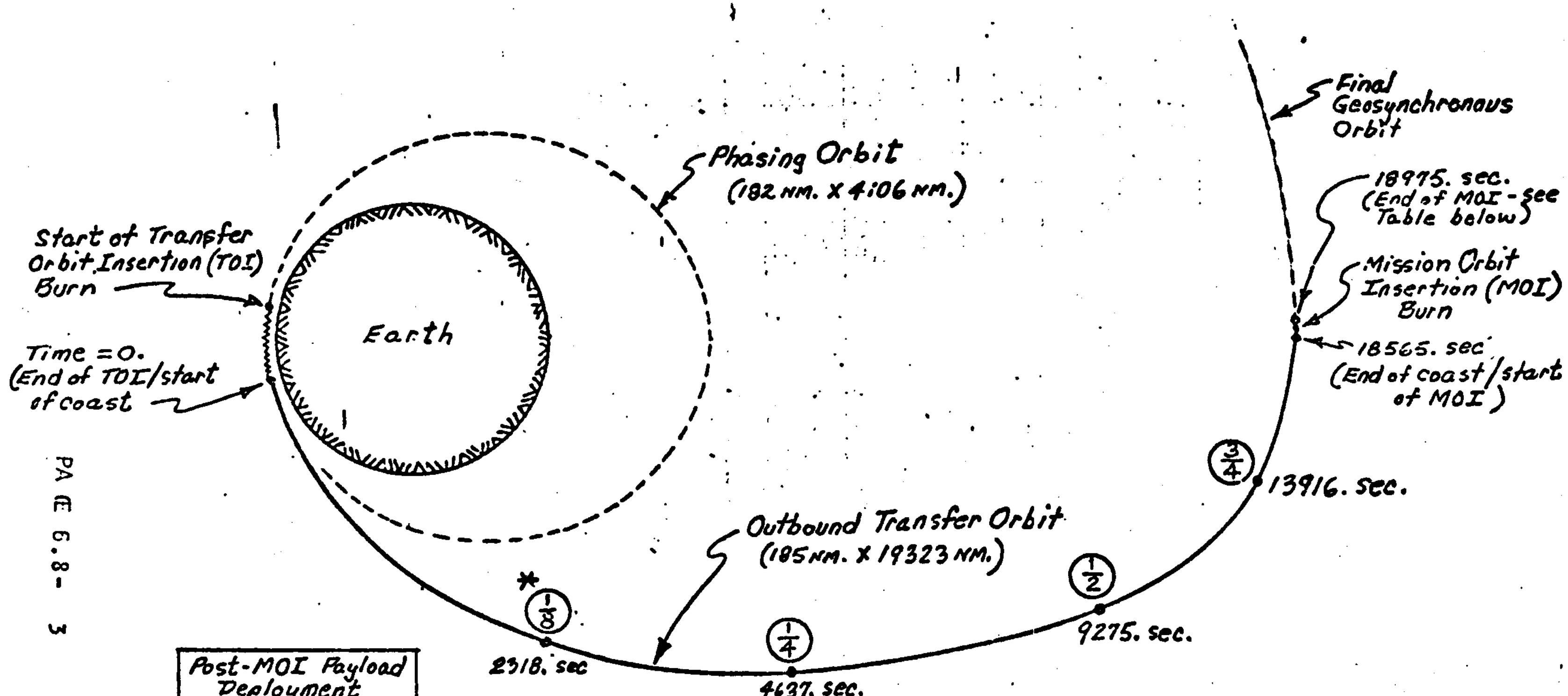
Insofar as this analysis is concerned the desired post-MOI payload deployment accuracy is used as the driver to determine the navigation update accuracy requirement between TOI and MOI as well as the IMU system error budget for the final or MOI burn. It is assumed that a perfect midcourse correction is executed and therefore the post-MOI payload deployment accuracy will be related solely to the propagation of navigation update errors from the point of update in the transfer orbit coast to the completion of the MOI burn, root-sum-squared (RSS'd), with the position and velocity errors arising during the MOI burn from IMU system errors.

The requirements for, and the impact of, navigation system performance in the period prior to TOI will be treated in a separate analysis where Delta-V penalties are of prime concern. Specifically, the initial condition errors present at the beginning of the TOI burn plus the closed-loop Delta-V errors arising during the burn from various attitude and acceleration measurement errors will determine the dispersion of the transfer orbit trajectory and hence the Delta-V penalty associated with the magnitude of any midcourse correction maneuver.

The transfer orbit trajectory is annotated with time marks measured from the completion of the TOI burn in Figure 1. In the subsequent data presented, zero time will be synonomous with the end of the TOI burn and the beginning of transfer orbit coast. The time reference will be particularly significant in terms of navigation systems categorized as Level 1 Autonomy (e.g. Star/Horizon/Landmark systems), which have a characteristically slow error convergence. On this time reference scale the time of navigation update is identical to the allotted tracking time for any particular system being considered.

It should be noted that the Post-MOI Payload Deployment Accuracy Table in Figure 1 uses 1 sigma values and not the 3 sigma values of the Tug Data Package. All the data herein is RSS, 1 sigma and where "per axis" values are used, the total RSS, 1 sigma equivalent values are obtained by multiplying by $\sqrt{3}$.

Figure 1
Outbound Leg Of TUG Geosynchronous Mission



* Circled fractions represent approximate portion of total transfer orbit coast time.

	Post-MOI Payload Deployment Accuracy	
	Position (NM, 1σ)	Velocity (FPS, 1σ)
Radial	23.3	23.3
Down-range	20.0	6.7
Cross Range	6.7	16.7
RSS	31.5	29.4

IMU SYSTEM ERROR BUDGET

The maximum attitude and acceleration errors that can be tolerated in the MOI burn are limited predominantly by the final downrange velocity error requirement of 6.7 FPS. Constant loci of total and downrange velocity errors as a function of per axis attitude and acceleration errors are plotted in Figure 2. A downrange velocity error budget of 5 FPS was chosen with 1.0 mrad/axis and 200 μg/axis attitude and acceleration error limits. Considering the 410 second MOI burn duration and the less than 1/2g thrust level for the single stage Tug, this initial error budget point should be compatible with any IMU system selected for the Shuttle and therefore, usable in the Tug program by virtue of commonality requirements. The effect of this IMU system error budget point selection is to implicitly define the allowable navigation system velocity update error contribution. The complete velocity error budgets for the IMU and navigation update systems are summarized in Table 1.

TABLE 1 - VELOCITY ERROR BUDGET

ERROR SOURCE	VELOCITY ERROR BUDGET (FPS) RADIAL	DOWN RANGE	CROSS RANGE	SUB-TOTALS (RSS)	
IMU: Attitude & Accelerometer Errrors During MOI Burn	*9.1	*5.0	*8.4	*13.3	
Propagation of Navigation Position and Velocity Update Errors From Any Point In Transfer Orbit to Completion of MOI Burn	21.5	4.5	14.4	26.2	
	23.3	6.7	16.7	29.4	TOTAL(RSS) Same as Data Pkg. Reqmt's.

* Corresponding to Initial Error Budget Point of Figure 2.

No attempt was made to represent the specifics of either a gimballed platform or strapdown IMU and dynamic effects were not explicitly modelled. The per axis attitude error was modelled as a pure bias which can only be interpreted as a rough approximation to the combined effects of alignment error plus some "average" integration of random, time correlated, bias, and g-sensitive drift rates. Similar comments apply to the modelling of the per axis acceleration error. The complete set of sensitivity coefficients for final position and velocity errors as a function of IMU system errors is given in Table 2.

Figure 2
Final TUG/Payload Velocity Error Due To Attitude & Accelerometer Errors During Mission Orbit Insertion Burn At Geosynchronous Altitude

(a) Total Velocity Error

(b) Downrange Velocity Error

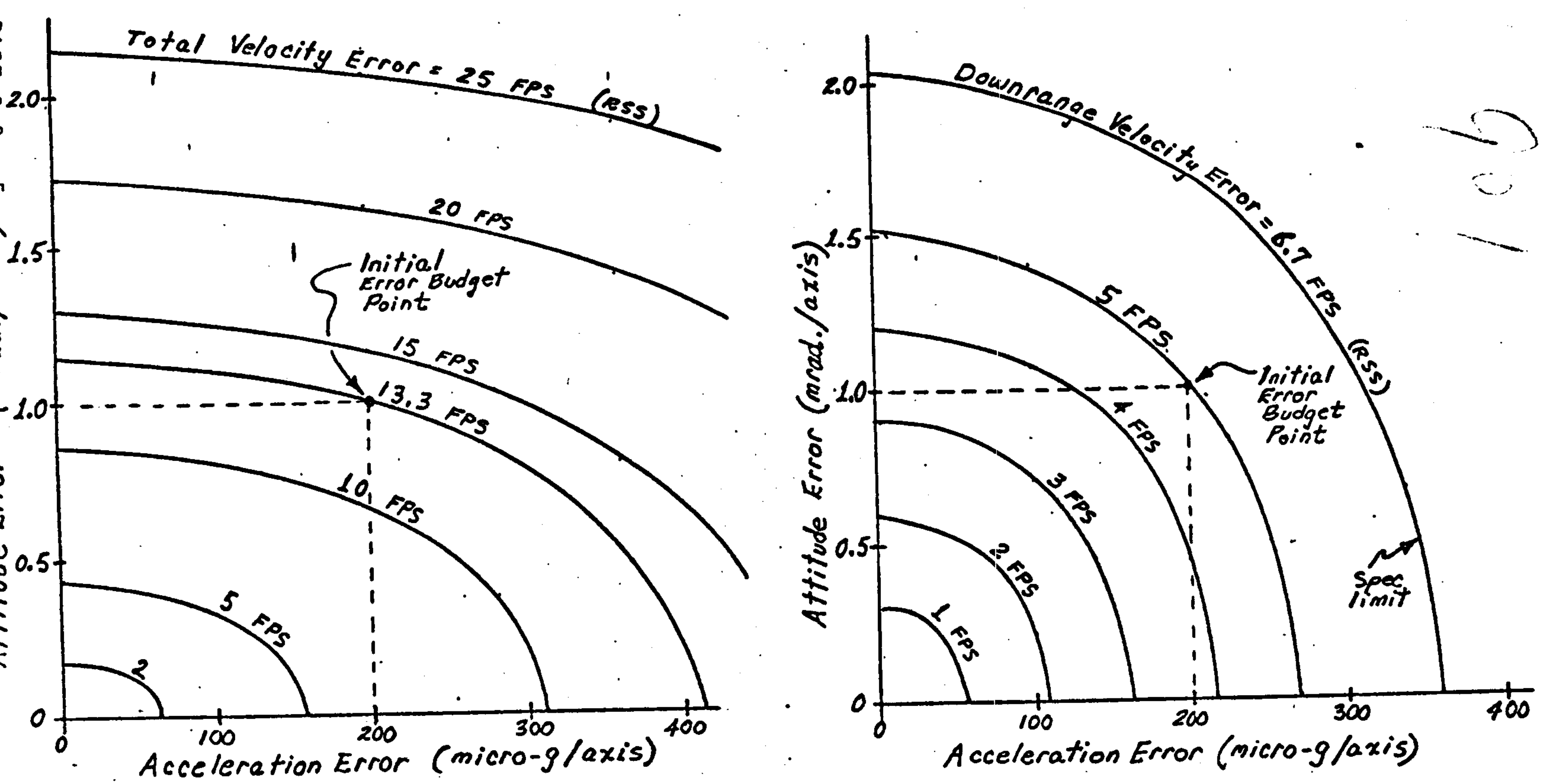


TABLE 2

FINAL (POST-MOI) POSITION AND VELOCITY ERROR SENSITIVITY
TO ATTITUDE AND ACCELEROMETER ERRORS IN MOI BURN

ERROR SOURCE	UNITS (NM)	FINAL POSITION ERROR SENSITIVITY				UNITS (FPS)	FINAL VELOCITY ERROR SENSITIVITY			
		RADIAL	DOWN RANGE	CROSS RANGE	TOTAL		RADIAL	DOWN RANGE	CROSS RANGE	TOTAL
ACCELERO-METER	NM / 100 μg/axis	0.063	0.063	0.063	0.109	FPS / 100μg/axis	1.863	1.862	1.863	3.226
ATTITUDE	NM / mrad/axis	0.254	0.089	0.238	0.359	FPS / mrad/axis	8.242	3.296	7.548	11.650

NAVIGATION UPDATE SYSTEM PERFORMANCE REQUIREMENTS

Navigation update position and velocity errors were propagated from various points in the transfer orbit coast to the end of MOI. The sensitivity of final position and velocity errors to navigation update errors at five time points is given in Tables 3 and 4.

Upon examination of these sensitivity coefficients in conjunction with the payload deployment accuracy requirements referenced in Figure 1 it is clear that final crossrange position error and final downrange velocity error are the drivers. Using the data in Tables 3 and 4, these two sensitivities are plotted in Figure 3 along with an arithmetic example of their use.

As time increases (say from 5,000 seconds on), velocity update errors have a <u>decreasing</u> impact on final crossrange position error and an <u>increasing</u> effect on final downrange velocity error. Conversely, position update errors have an <u>increasing</u> effect on final crossrange position error and a <u>decreasing</u> effect on final downrange velocity error. At the latest theoretical update point just prior to MOI (i.e., at 18565 seconds), final crossrange position error is virtually dependent on position update error only and final downrange velocity error is dependent on the combined effect of velocity update error and IMU system velocity error contribution during the MOI burn.

In the range of the most likely navigation update occurrence (say 1/4 to 3/4 of coast time), where a midcourse correction of reasonable Delta-V penalty can be realized, the <u>joint</u> effect of navigation update position <u>and</u> velocity errors must be considered. Hence, no unique curve can be drawn which defines an absolute boundary for simultaneous position and velocity navigation update errors in this middle region. A "working" approximation to <u>joint</u> upper boundaries or limits for navigation position and velocity update errors can be developed by working backwards from the latest time point, just prior to MOI, where the effect of position and velocity update errors are uncoupled. This procedure was used to develop the typical, but non-unique, set of joint upper boundaries shown in Figure 4.

In addition to the final point, the joint boundaries at 0 and 4637 seconds were determined as described below and a relatively smooth curve was faired between these three data points.

- At time = 0; Velocity and position error allotments of 1.48 FPS RSS and 1688 FT RSS, yielding the combined allowable limit on final crossrange position error (the individual contributions of velocity and position error were approximately equal).

TABLE 3

FINAL (POST-MOI), POSITION AND VELOCITY ERROR SENSITIVITY TO NAVIGATION UPDATE VELOCITY ERROR

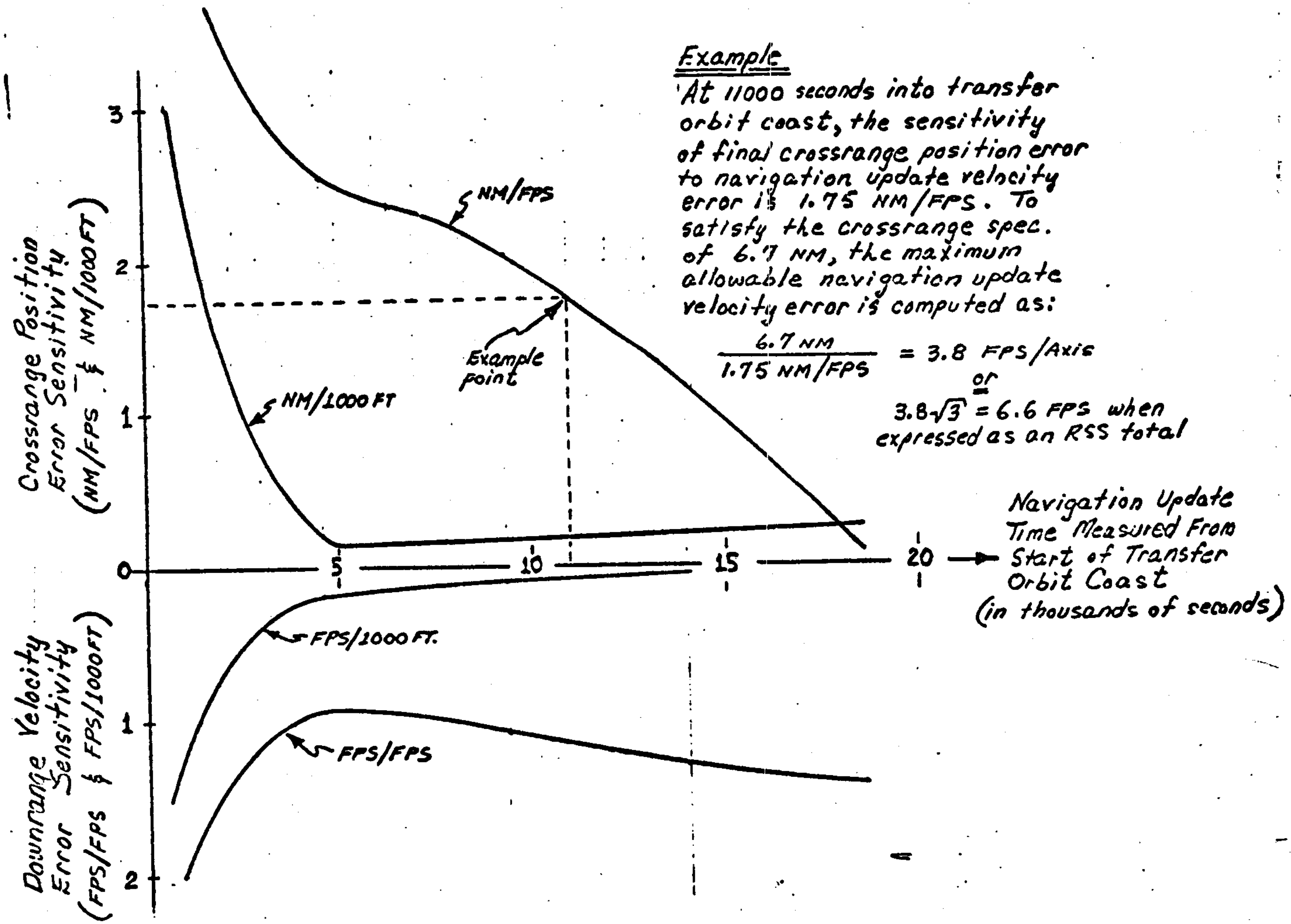
TIME OF VELOCITY UPDATE MEASURED FROM START OF TRANSFER ORBIT COAST (SECONDS)	FINAL POSITION ERROR SENSITIVITY NM/(FPS/AXIS)				FINAL VELOCITY ERROR SENSITIVITY FPS/(FPS/AXIS)			
	RADIAL	DOWN-RANGE	CROSS-RANGE	TOTAL	RADIAL	DOWN-RANGE	CROSS-RANGE	TOTAL
0.	14.089	11.448	5.534	18.979	11.025	2.783	1.310	11.446
4637.	5.254	2.969	2.572	6.560	3.812	0.967	0.658	3.987
9275.	2.669	2.073	2.047	3.971	2.240	1.082	1.052	2.701
13916.	1.232	1.150	1.150	2.040	1.613	1.319	1.317	2.466
18565	0.097	0.097	0.097	0.168	1.416	1.414	1.414	2.450

TABLE 4

FINAL (POST-MOI), POSITION AND VELOCITY ERROR SENSITIVITY TO NAVIGATION UPDATE POSITION ERROR

TIME OF POSITION UPDATE MEASURED FROM START OF TRANSFER ORBIT COAST (SECONDS)	FINAL POSITION ERROR SENSITIVITY NM/(1000 FT/AXIS)				FINAL VELOCITY ERROR SENSITIVITY FPS/(1000 FT/AXIS)			
	RADIAL	DOWN-RANGE	CROSS-RANGE	TOTAL	RADIAL	DOWN-RANGE	CROSS-RANGE	TOTAL
0.	11.659	9.735	4.861	15.948	9.305	2.175	1.010	9.609
4637.	0.889	0.403	0.193	0.996	0.618	0.172	0.147	0.658
9275.	0.390	0.185	0.164	0.462	0.210	0.083	0.081	0.239
13916.	0.266	0.217	0.216	0.406	0.083	0.039	0.039	0.099
18565.	0.233	0.233	0.233	0.403	0.006	0.003	0.003	0.008

Figure 3
Final (post-MOI) Crossrange Position & Downrange Velocity Error Sensitivities of TUG/Payload To Navigation Position & Velocity Update Errors



Example
At 11000 seconds into transfer orbit coast, the sensitivity of final crossrange position error to navigation update velocity error is 1.75 NM/FPS. To satisfy the crossrange spec. of 6.7 NM, the maximum allowable navigation update velocity error is computed as:

$$\frac{6.7 \text{ NM}}{1.75 \text{ NM/FPS}} = 3.8 \text{ FPS/Axis}$$

or

$3.8\sqrt{3} = 6.6$ FPS when expressed as an RSS total

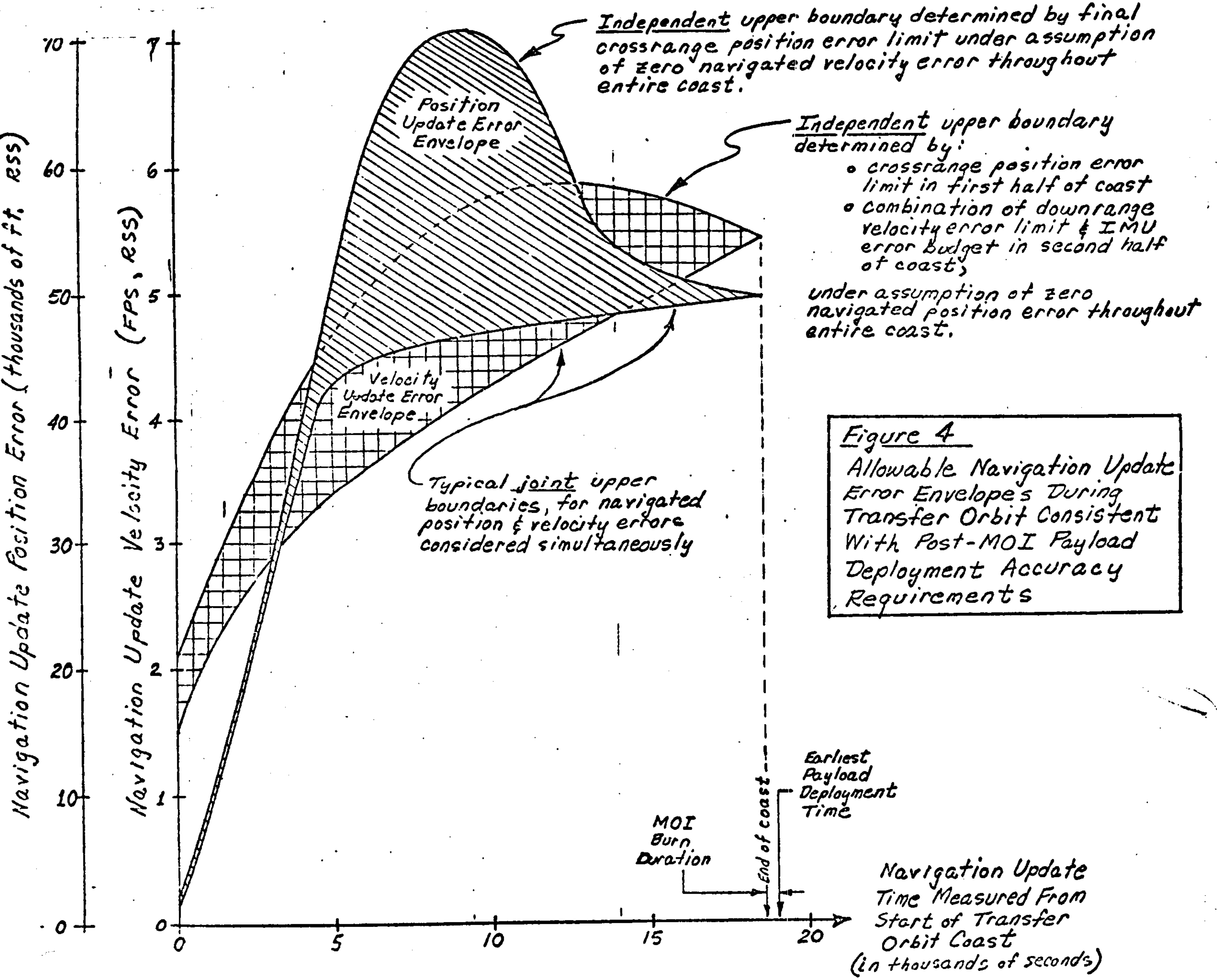


Figure 4
Allowable Navigation Update Error Envelopes During Transfer Orbit Consistent With Post-MOI Payload Deployment Accuracy Requirements

- o At time = 4637 seconds; Velocity and position error allotments of 3.3 FPS RSS and 41138 FT RSS, yielding simultaneous final allowable limits on radial position (23.3 NM), crossrange position (6.7 NM), and downrange velocity, (*4.5 FPS).

- o At time = 18565 seconds; Velocity error allotment of 5.5 FPS RSS, yielding limit on downrange velocity (*4.5 FPS) and position error allotment of 49805 FT RSS yielding limit on crossrange position error, (6.7 NM).

The <u>independent</u> upper boundaries (i.e., those obtained by considering position error maximums in the presence of perfect velocity data and vice versa) are also plotted in Figure 4 to provide a graphic indication of those regions where velocity and position error allotments may be traded off against each other in significant amounts while still satisfying final payload deployment accuracies. It is noted that to within 2 or 3 significant figures there is no difference between the independent and joint upper boundaries at the last point due to the uncoupling of position and velocity update errors mentioned previously.

In general, if the performance specifications of a particular navigation update system (corresponding to the appropriate tracking time), fall within the error envelopes of Figure 4, the system may be classed as unsuitable. If, on the other hand, both position and velocity errors are well below the <u>joint</u> upper boundaries at the time point in question, the system may be classed as suitable. For marginal cases, or where one parameter (i.e., position or velocity) is within the envelope, and the other is below, Figure 3 and/or Tables 3 and 4 (interpolating where necessary) should be used to make the final decision.

If it is necessary to discard or modify the IMU system error budget selected for this analysis, Table 2 can be used to generate a new velocity error budget similar to Table 1. The effect of a new velocity error budget for the navigation update system will manifest itself in the second half of the velocity update error envelope of Figure 4.

* 4.5 FPS in accordance with Table 1 to yield a total of 6.7 FPS when RSS'd with IMU velocity error budget of 5.0 FPS.

6.8.2 FINAL RESULTS OF SPACE TUG NAVIGATION SYSTEM PERFORMANCE REQUIREMENTS ANALYSIS INCLUDING DELTA-V PENALTIES AND AUTONOMY LEVEL COMPATIBILITY FOR THE GEOSYNCHRONOUS PAYLOAD DEPLOYMENT MISSION - SINGLE STAGE.

REFERENCE: B81M049-73026, "Results of Space TUG Navigation System Performance Requirements Analysis For The Geosynchronous Payload Deployment Mission", June 12, 1973.

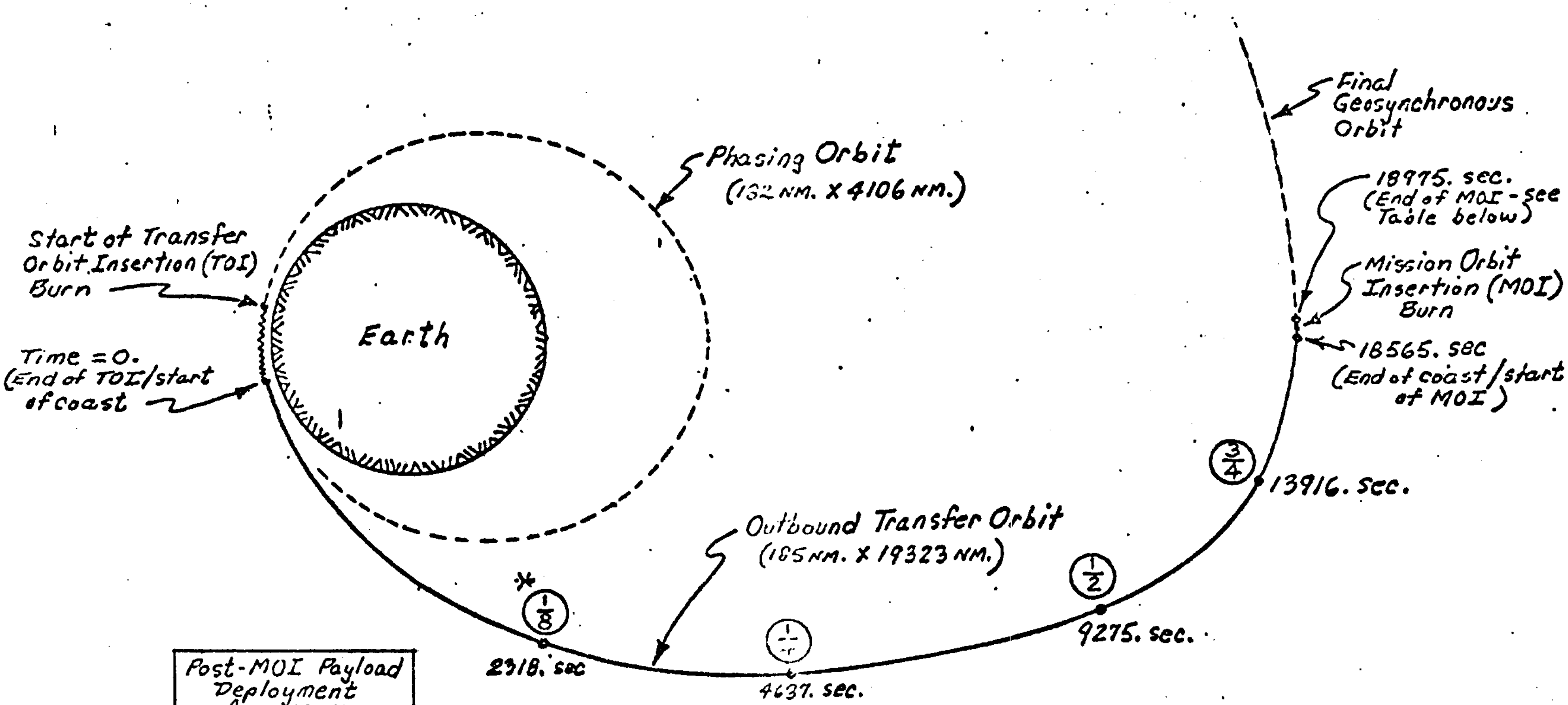
RESULTS SUMMARY

Space TUG navigation system performance requirements are driven by the payload deployment accuracy requirements shown in Figure 1 as well as the practical necessity of minimizing the delta-V penalty budget to some level less than 50 fps
Combining the results of the memo referenced above with those of the analysis discussed herein, yields the following conclusions with respect to the navigation system performance requirements of the single-stage space TUG in the geosynchronous payload deployment mission.

- Steady-state navigation performance in phasing orbit: $\leq$ 5000 ft RSS and $\leq$ 2 fps RSS.
- Dynamic navigation performance in transfer orbit: error convergence to < 20000 ft RSS and < 3.5 fps in no more than 100 minutes of tracking time after start of transfer orbit coast.
- IMU performance in transfer orbit insertion (TOI), and mission orbit insertion (MOI), burns: $\leq$ 1 mrad/axis attitude error and $\leq$ 200 μg/axis accelerometer error.

These performance numbers are not strictly unique since some trading off against each other (e.g., steady-state degradation vs dynamic improvement, etc....), can be made. Such tradeoffs will not affect any appreciable change however, and more significantly they will not change the next conclusion regarding autonomy level compatibility.

Figure 1
Outbound Leg Of TUG Geosynchronous Mission



* Circled fractions represent approximate portion of total transfer orbit coast time.

	Post-MOI Payload Deployment Accuracy	
	Position (NM, 1σ)	Velocity (FPS, 1σ)
Radial	23.3	23.3
Down-range	20.0	6.7
Cross Range	6.7	16.7
RSS	31.5	29.4

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If delta-V penalties are to be kept within acceptable bounds (i.e., less than 50 fps), autonomy level 1 navigation systems, as typified by star tracker/horizon scanner sensor complements, must be rejected as viable space TUG candidates. Using dynamic results in low earth orbit and synchronous orbit (i.e., the only readily available data for star/horizon sensor systems), it is "optimistically estimated" that such systems typifying autonomy level 1 would not converge until somewhere between the 50% and 75% point of the transfer orbit thereby imposing an intolerable delta-V penalty of 100 fps to 300 fps

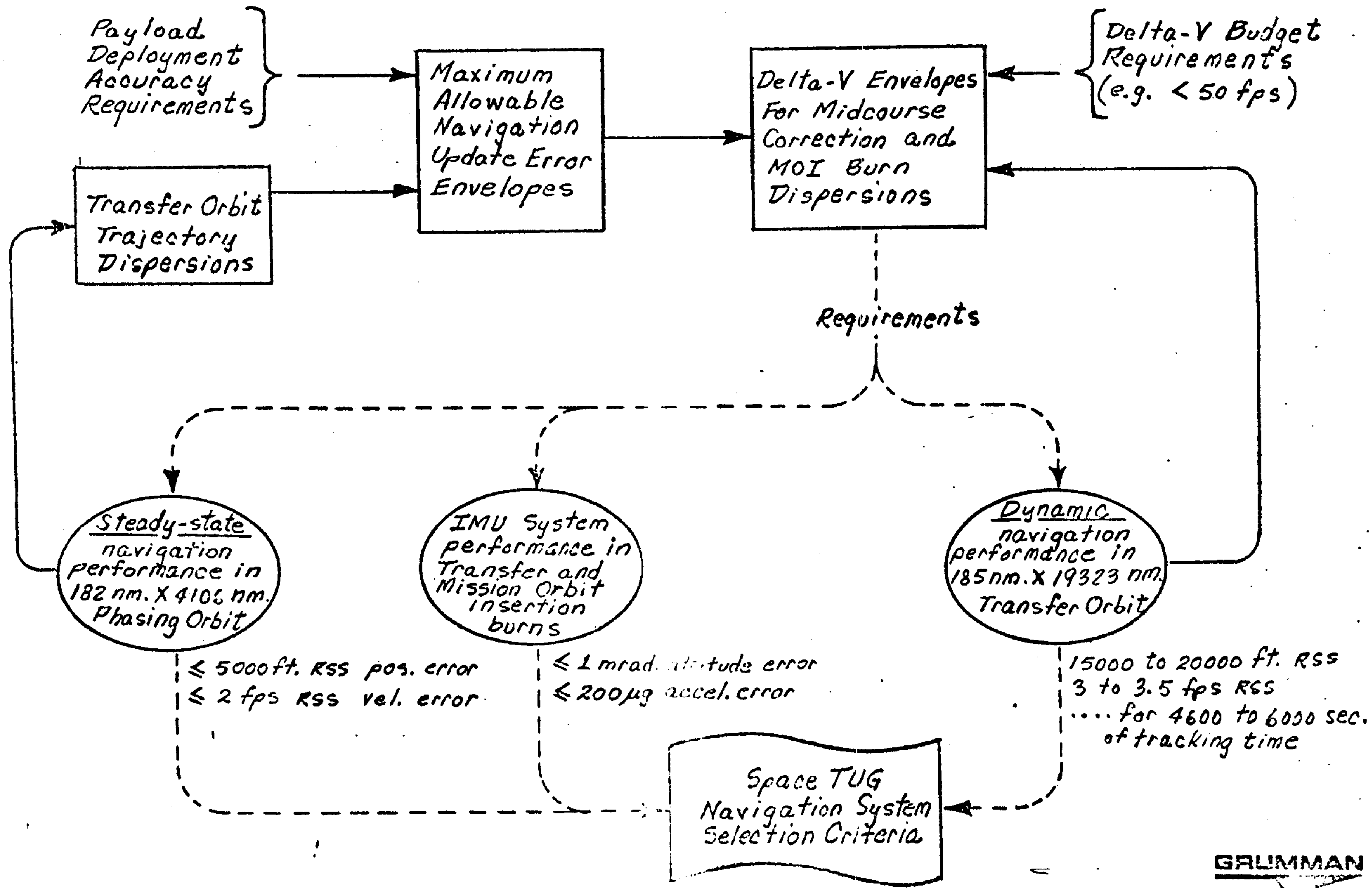
ANALYSIS FRAMEWORK

Figure 2 provides a simplified flow diagram of the analysis framework used in developing the space TUG navigation system performance requirements quoted above and dovetails the work of the reference with the additional analysis covered herein. The reference determined what the maximum navigation update error envelopes had to be in order to satisfy the payload deployment accuracy requirements including the effect of IMU errors in the final or MOI burn. A second set of maximum navigation update error envelopes were generated herein based on a fraction of the actual trajectory dispersion obtained as a result of initial condition errors at the start of the TOI burn plus the contribution of IMU errors during the TOI burn. The fraction used was 20% which is equivalent to requiring that the navigation update error be no more than 20% of the actual trajectory dispersion before a midcourse correction can be considered feasible. The composite or combined maximum allowable navigation update error required at any time point in the transfer orbit is then defined as the lesser of these two envelopes.

The delta-V penalties associated with the transfer orbit trajectory dispersion are divided into two categories. The impulsive delta-V penalty necessary to put the Space TUG on a transfer conic which will intercept a target vector defined as the start point of the MOI burn for a nominal trajectory is denoted ΔV_{mc} . The impulsive delta-V penalty due to not being on the nominal transfer conic when MOI is reached is denoted ΔV_{MOI} , and in effect is an MOI dispersion penalty allotted to the finite MOI burn. At any point in the transfer orbit where a midcourse correction is postulated the total delta-V penalty ΔV_T , is computed as the sum of ΔV_{mc} and ΔV_{MOI} .

The transfer orbit trajectory dispersion is determined by the steady-state navigation performance in the phasing orbit, or in other words, the initial condition errors present at the start of the TOI burn plus the effect of IMU errors. On the other hand, the dynamic performance of the navigation system determines the earliest point at which a midcourse correction can be made by determining when the system's error drops below the composite maximum allowable navigation update error boundary described previously.

Figure 2 Analysis Framework For Development of Space TUG Navigation System Performance Requirements



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DISCUSSION OF RESULTS

Within the analysis framework described, a number of iterations using various steady-state initial conditions were made, and 5000 ft RSS, 2 fps RSS, and the IMU quality of the reference (i.e., 200 μg/axis and 1 mrad/axis) were chosen as a baseline requirement for the Space Tug navigation system. The corresponding delta-V penalties together with the composite maximum allowable navigation position and velocity update errors are shown in equivalent time frames in Figure 3. For the set of initial conditions specified (i.e., the baseline requirement), the contributions of position error, velocity error and IMU errors are approximately equal in terms of subsequent trajectory dispersion and reduction of any one of them to zero would only reduce the total effect less than 25% in any "RSS sense". This was part of the rationale for specifying this set as the steady-state navigation performance and the rest of the rationale is based on the fact that 5000 ft and 2 fps error limits would not be incompatible with or preclude any specific autonomy level at the outset, although they could be borderline for level 1.

As described previously, and as shown in Figure 3, the maximum navigation position and velocity update error limits are given as the lesser of the limits required to satisfy payload deployment accuracy or 20% of the actual trajectory dispersion. In terms of allowable velocity error, the limit based on satisfying payload deployment accuracy is clearly the controlling maximum while the 20% limit is the dominant boundary for the position error.

If the total delta-V penalty ΔV_T, is to be less than 50 fps, Figure 3 shows that the dynamic performance of the navigation system must be compatible with achieving a position error of < 20000 ft RSS and a velocity error of < 3.5 fps RSS within 6000 secs (i.e., 100 minutes) from the start of transfer orbit coast.

As stated in the Results Summary, it is concluded from presently available analysis results that autonomy level 1 navigation systems as typified by star/horizon systems cannot meet this 100 minutes performance level in highly eccentric orbits such as the transfer orbit of the Space TUG geosynchronous mission profile.

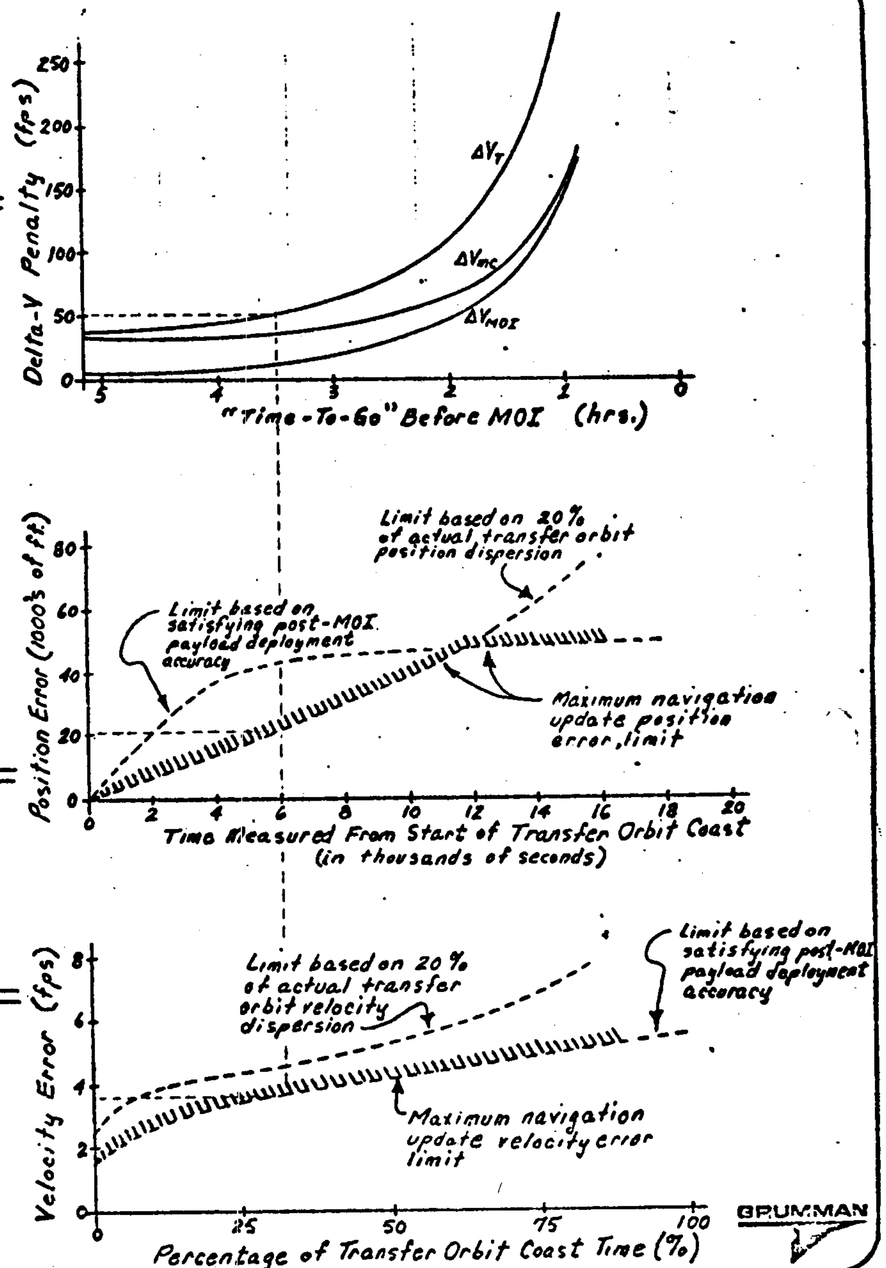
Preliminary estimates of the delta-V penalty regions as a function of navigation system autonomy level are given in Figure 4. The 5000 ft curve in Figure 4 is the same as the ΔV_T curve in Figure 3 and the 10000 ft and 20000 ft delta-V curves have been added to illustrate the delta-V sensitivity to initial position error.

Figure 3

Delta-V Penalties As A Function Of Time & Corresponding Navigation Update Accuracy Requirements During The Transfer Orbit Coast Phase For One Set of Pre-TOI Initial Conditions*

Equivalent Time References			Maximum Navigation Update Error Limit (RSS-1 sigma)		Delta-V Penalties (fps-RSS-1 sigma)		
Time To Go Before MOI Burn (hrs.)	Time Measured From Start of Transfer Orbit Coast (sec)	Percentage of Transfer Orbit Coast Time (%)	Velocity (fps)	Position (ft)	Midcourse Correction ΔV_{mc}	MOI Dispersion ΔV_{MOI}	Total ΔV_T
5.16	0.	0.	1.5	1524.	32.	4.	36.
4.51	2318.	12.5	2.8	7984.	30.	5.	35.
3.87	4637.	25.	3.3	16243.	33.	10.	43.
2.58	9275.	50.	4.1	35496.	47.	28.	75.
1.29	13916.	75.	4.8	48300.	104.	92.	196.
0.85	15500.	83.5	5.0	48900.	180.	173.	353.

Equivalent to allowable navigation system tracking time to reduce position and velocity update error below specified limit



*Initial conditions (1 sigma), at start of TOI burn:

- NAVIGATION ERROR
  - Position: 5000 ft-RSS
  - Velocity: 2 fps-RSS
- IMU SYSTEM ERRORS
  - Acceleration: 200µg/axis
  - Attitude: 1.0 mrad./axis

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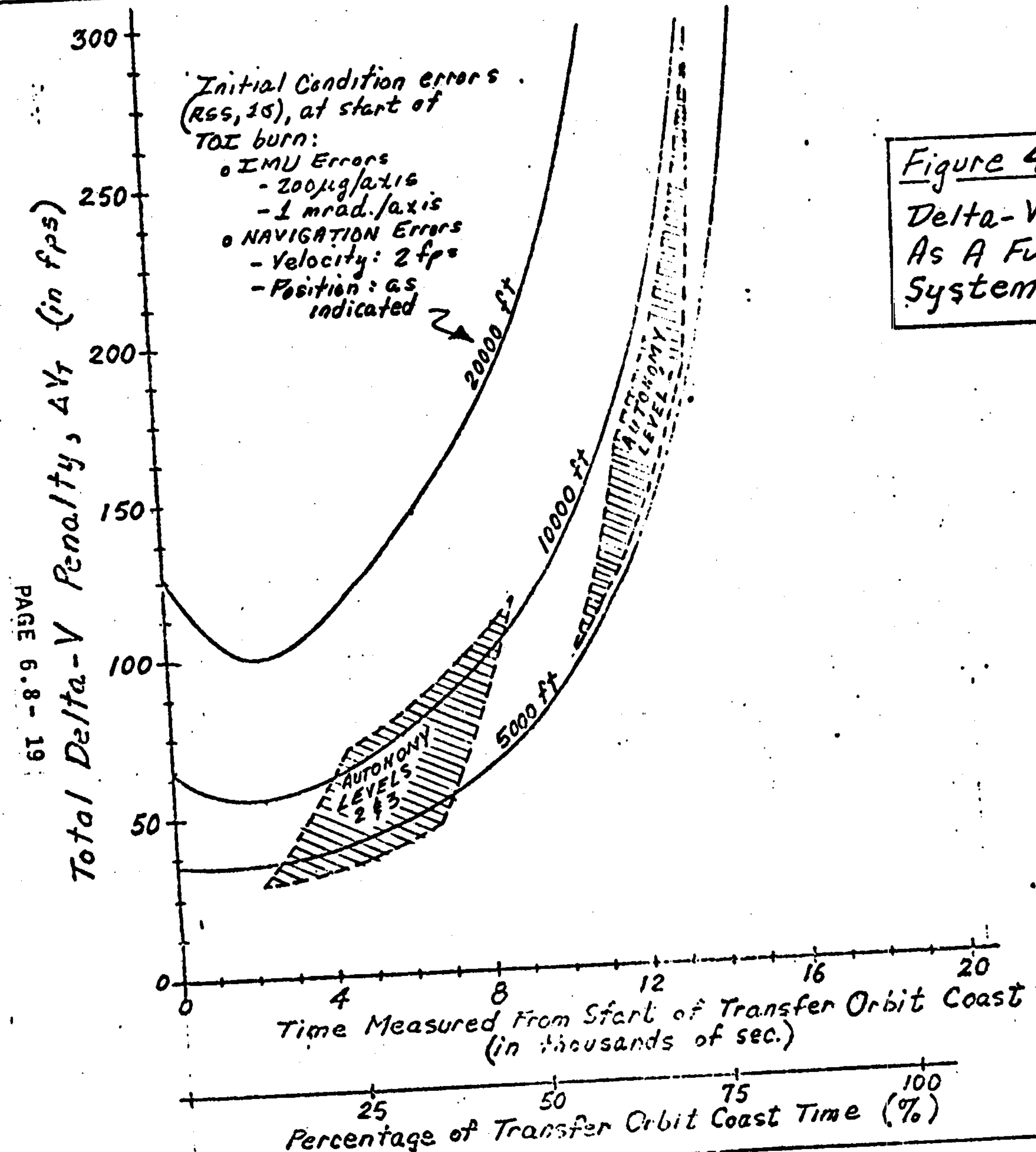

Figure 4

Delta-V Penalty Regions As A Function of Navigation System Autonomy Level

In conclusion, the reader is advised that Attachment A to this memo documents all the numerical sensitivity coefficients and computational procedures used to generate the data presented herein and may be alternately used to generate new delta-V curves and trajectory dispersions for any other set of initial conditions or IMU quality that may be desired.

ATTACHMENT A

Attachment A provides the documentation of the fundamental sensitivity coefficients (i.e., partial derivatives), used to generate the trajectory dispersion and delta-V penalty curves presented in Space TUG memorandum #B81M049-73042, entitled "Final Results of Space TUG Navigation System Performance Requirements Analysis Including Delta-V Penalties and Autonomy Level Compatibility For The Geosynchronous Payload Deployment Mission", dated July 13, 1973. Using the data in this attachment the user may compute transfer orbit trajectory dispersion curves as a function of initial position and velocity errors as well as IMU accelerometer and attitude errors that are different from those used in the above referenced memo. The new trajectory dispersion data can then be used to develop correspondingly different delta-V penalty curves.

Figure 1A illustrates the complete computational procedure to be used when developing new data. The precise values which define the 10 sensitivity coefficient time histories roughly depicted in Figure 1A are given in Tables 1 thru 5. Each table cross indexes the type of data in that table with the same computational nomenclature shown in Figure 1A. As a self-check in using the material in this attachment the user can recompute the data for one or more of the time points tabulated in Figure 3 of the referenced memo, with the set of initial conditions specified.

From a technical point of view, the only computation in Figure 1A that may not be immediately obvious is the multiplication of the total trajectory velocity dispersion Δv, by $\sqrt{2}$ to obtain the midcourse delta-V penalty $\Delta V_{mc\Delta v}$. The rationale for this procedure stems from the fact that the delta-V penalties were obtained by solving the Lambert's problem for velocity and position perturbations from the nominal transfer orbit on the basis of taking one error component per axis, one at a time, and then RSS'ing the results. The effect of this procedure is that when a velocity perturbation (say 100 fps in the X, Y, or Z direction) is used, the resultant impulsive delta-V correction obtained from Lambert's solution is the same amount (i.e., 100 fps). This occurs since no position perturbation from the nominal is being simulated at the same time as a velocity perturbation and therefore Lambert's solution yields the same amount of impulsive delta-V as the original perturbation because the vehicle is in effect, on the proper or nominal transfer conic and only its velocity need be corrected.

If a constant magnitude per axis velocity perturbation is denoted as Δv_i for i = x, y, or z, then the total RSS velocity perturbation Δv, is given by $\Delta v = \Delta v_i \sqrt{3}$. In addition, the RSS total impulsive delta-V penalty would be $\Delta v_i \sqrt{6}$ after RSS'ing the six results (i.e. + and - for each of three axes).

In the first order relationship,

$$\Delta V_{mc\Delta v} = \left(\frac{\partial V_{mc\Delta v}}{\partial \Delta v} \right) \Delta v$$

it is recognized that,

$$\Delta V_{mc\Delta v} = \Delta V_i \sqrt{6}$$
$$\Delta v = \Delta V_i \sqrt{3}$$

and therefore, $$\frac{\partial V_{mc\Delta v}}{\partial \Delta v} = \sqrt{2}$$ as

used in Figure 1A.

Figure-1A Computational Procedure For Determining Trajectory Dispersion Delta-V Penalties

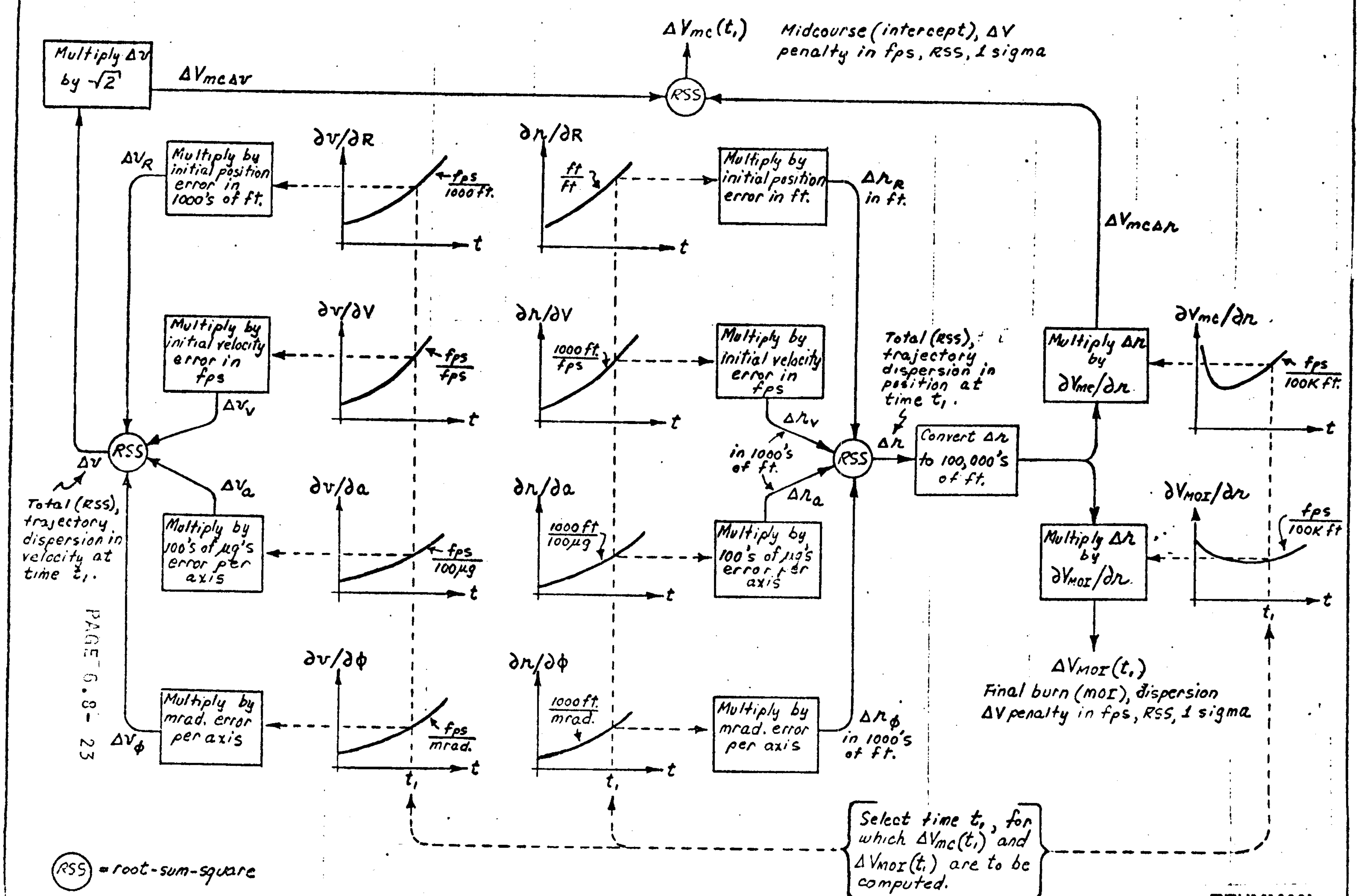

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TABLE 1

DELTA-V PENALTY SENSITIVITIES TO TRANSFER ORBIT POSITION DISPERSION, Δr

TIME MEASURED FROM START OF TRANSFER ORBIT (sec.)	MIDCOURSE DELTA-V PENALTY SENSITIVITY TO TRANSFER ORBIT POSITION DISPERSION, Δr $\partial V_{mc}/\partial r$ (fps/100K ft.)	MISSION ORBIT INSERTION (MOI), BURN DELTA-V PENALTY SENSITIVITY TO TRANSFER ORBIT POSITION DISPERSION, Δr $\partial V_{MOI}/\partial r$ (fps/100K ft.)
0.	358.25	5[illegible].17
2318.	28.59	12.67
4637.	15.13	11.80
9275.	15.90	15.54
13916.	30.49	30.48
15500.	46.22	46.63
Computation of Figure 1A nomenclature	$\Delta V_{mc\Delta r} = \left(\frac{\partial V_{mc}}{\partial r}\right)\Delta r$	$\Delta V_{MOI} = \left(\frac{\partial V_{MOI}}{\partial r}\right)\Delta r$

TABLE 2

TRANSFER ORBIT DISPERSION SENSITIVITY
TO INITIAL (PRE-TOI), NAVIGATED POSITION ERROR, ΔR

TIME MEASURED FROM START OF TRANSFER ORBIT (sec.)	VELOCITY DISPERSION SENSITIVITY $\partial v/\partial R$ (fps/1000 ft.)	POSITION DISPERSION SENSITIVITY $\partial r/\partial R$ (ft./ft.)
0.	1.129	1.442
2318.	2.691	5.442
4637.	2.920	10.959
9275.	3.513	23.641
13916.	4.426	39.550
15500.	4.698	44.131
18560.	5.681	57.665
Computation of Figure 1A nomenclature	$\Delta v_R = \left(\frac{\partial v}{\partial R}\right)\Delta R$	$\Delta r_R = \left(\frac{\partial r}{\partial R}\right)\Delta R$

TABLE 3

TRANSFER ORBIT DISPERSION SENSITIVITY
TO INITIAL (PRE-TOI), NAVIGATED VELOCITY ERROR, ΔV

TIME MEASURED FROM START OF TRANSFER ORBIT (sec.)	VELOCITY DISPERSION SENSITIVITY $\partial v/\partial V$ (fps/fps)	POSITION DISPERSION SENSITIVITY $\partial r/\partial V$ (1000. ft./fps)
0.	1.443	0.624
2318.	2.662	5.149
4637.	3.187	11.359
9275.	4.509	29.238
13916.	5.110	45.365
15500.	5.652	54.342
18560.	6.588	67.320
Computation of Figure 1A nomenclature	$\Delta v_V = \left(\frac{\partial v}{\partial V}\right)\Delta V$	$\Delta r_V = \left(\frac{\partial r}{\partial V}\right)\Delta V$

TABLE 4

TRANSFER ORBIT DISPERSION SENSITIVITY
TO ACCELERATION MEASUREMENT ERROR Δa, IN THE TOI BURN

TIME MEASURED FROM START OF TRANSFER ORBIT (sec)	VELOCITY DISPERSION SENSITIVITY $\partial v/\partial a$ (fps/100 μg)	POSITION DISPERSION SENSITIVITY $\partial r/\partial a$ (1000 ft./100 μg)
0.	3.320	0.712
2318.	5.470	10.231
4637.	6.880	23.599
9275.	8.640	54.822
13916.	11.715	101.510
15500.	13.955	135.310
18560.	15.230	153.197
Computation of Figure 1A nomenclature	$\Delta V_a = \left(\frac{\partial v}{\partial a}\right)\Delta a$	$\Delta r_a = \left(\frac{\partial r}{\partial a}\right)\Delta a$

TABLE 5

TRANSFER ORBIT DISPERSION SENSITIVITY
TO ATTITUDE ERROR $\Delta\Phi$, IN THE TOI BURN

TIME MEASURED FROM START OF TRANSFER ORBIT (sec.)	VELOCITY DISPERSION SENSITIVITY $\partial v/\partial\phi$ (fps/mrad)	POSITION DISPERSION SENSITIVITY $\partial r/\partial\phi$ (1000 ft./mrad)
0.	7.877	1.583
2318.	6.566	18.127
4637.	5.011	29.153
9275.	4.207	45.660
13916.	4.585	57.725
15500.	5.147	61.465
18560.	5.831	72.105
Computation of Figure 1A nomenclature	$\Delta v_\phi = \left(\frac{\partial v}{\partial\phi}\right)\Delta\phi$	$\Delta r_\phi = \left(\frac{\partial r}{\partial\phi}\right)\Delta\phi$

6.10 RENDEZVOUS AND DOCKING ANALYSIS

Rendezvous and docking analyses performed are described in the following sections, 6.10.1 through 6.10.5, the subjects of these analyses being the following:

6.10.1 Rendezvous with Payload, ΔV and Approach Angle,

6.10.2 Rendezvous with Payload, Effects of Off-Nominal TPI,

6.10.3 Docking to Spacecraft with small residual angular rates,

6.10.4 Rendezvous, Station Keeping, and Docking to Non-rotating Spacecraft,

6.10.5 Study plan to demonstrate feasibility of Automatic Rendezvous , Automatic Direct Docking, and TV Remote Rendezvous and Docking.

6.10.1

SUBJECT: RENDEZVOUS WITH PAYLOAD, ΔV AND APPROACH ANGLE

Summary:

Variations in ΔV and approach angle for a tug rendezvous with a payload in goesynchronous orbit were determined as a function of tug initial position relative to the P/L and of tug translational acceleration level.

EFFECTS OF VARIATIONS IN TUG INITIAL POSITION

The Lambert Routine was used to generate data for the terminal phase following circularization. At the time of TPI, the P/L has the following state:

Altitude	=	19323 n.mi.
X	=	119801200. f
Y	=	69167262.
Z	=	0.
$\dot{X}$	=	5043.74 f/s
$\dot{Y}$	=	−8736.0134
$\dot{Z}$	=	0.

The tug, at the time of TPI, is located at a point within ± 10 n. mi. from each of the following:

Behind P/L:	10 n.mi.
Below P/L :	40 n.mi.

The terminal phase, TPI and TPF, is restricted to be completed in a central angle of 30°, corresponding to a time of flight of 119.67 min.

The results, in terms of ΔV and approach angle vs. tug initial position, are given in Figs. 1 and 2.

Note in Fig. 1 that the total ΔV is smaller for the tug behind 20 than for the tug behind 0. This phenomenon appears to be the result of restricting the central angle to 30°.

From Fig. 2 it is seen that the approach angle varies between -58 and -96 degrees for initial positions of the tug within ± 10 from 10 n.mi. behind and within ± 10 from 40 n.mi. below.

EFFECTS OF VARIATIONS IN TUG THRUST LEVELS

The rendezvous routine was used to generate data for the TPF. The initial state of the P/L is the same as that given in the previous section. The initial position of the tug is 10 n.mi. behind and 40 n.mi. below the P/L, and the initial relative velocity of the tug is that generated by the TPI. The tug initial state is then:

X	=	119560340. f
Y	=	69098361.
Z	=	0.
$\dot{X}$	=	5082.7153 f/s
$\dot{Y}$	=	- 8723.7612
$\dot{Z}$	=	0.
Mass	=	495 slugs

The TPF consists of 4 gates, i.e., selected ranges at which tolerances on range rate and LOS rate must be met. If, at a range gate, the tolerances are met, no action is taken; but if the tolerances are not met, the APS jets are turned on in a manner so that the tolerances become satisfied. The following range gates were used:

Range, f	Tolerances: Range Rate, f/s Min	Range Rate, f/s Max	LOS Rate, d/s Min	LOS Rate, d/s Max
12160.	18.	22.	-0.1	+0.1
6080.	11.7	14.3	↓	↓
1000.	6.3	7.7	↓	↓
300.	1.8	2.2	↓	↓

The I_{sp} assumed for the APS jets was 230. The initial mass of the tug was set at 495 slugs. At the end of TPF (at 300 ft range), the mass is 493 slugs. Thus the mass is approximately constant during the maneuver. The APS thrust levels used to control range rate and LOS rate were set at 200,100,50 and 25 lbs. For a tug mass = 495 slugs, these thrust levels correspond to the following tug accelerations:

Thrust, Lb	Acceleration, f/s^2
200.	0.404
100.	0.202
50.	0.101
25.	0.0505

The TPF ΔV requirement as a function of APS total thrust is given in Fig. 3 and as a function of tug acceleration is given in Fig. 4. It is seen that the minimum ΔV requirement , 28 f/s, is obtained at a tug longitudinal acceleration of approximately 0.1 f/s^2 and that the ΔV requirement is increasing rapidly at smaller tug acceleration levels. At a longitudinal acceleration of 0.1 f/s^2, a variation of lateral acceleration produces no change in ΔV.

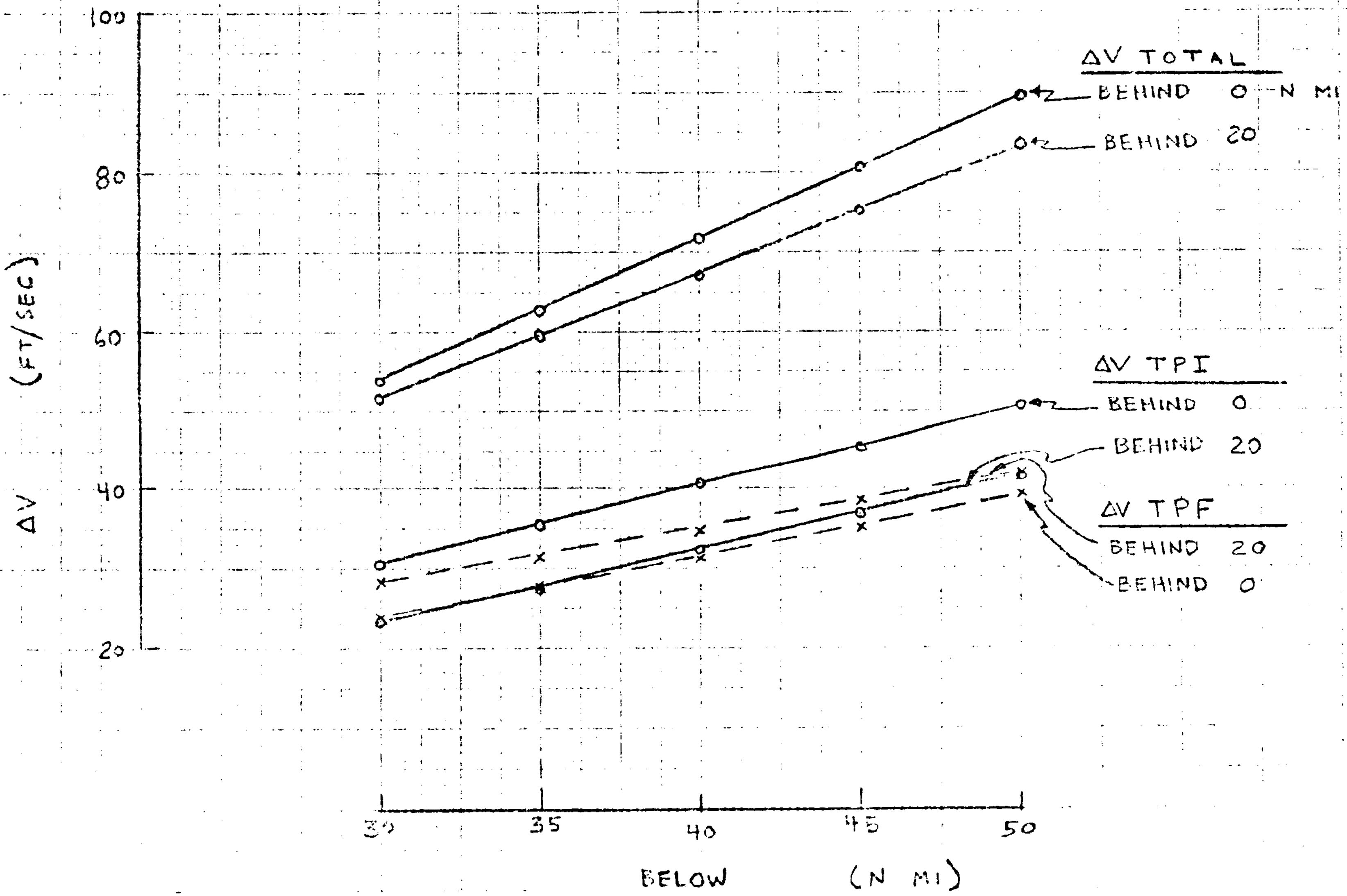


FIG. 1 ΔV VS. TUG INITIAL POSITION RELATIVE TO P/L

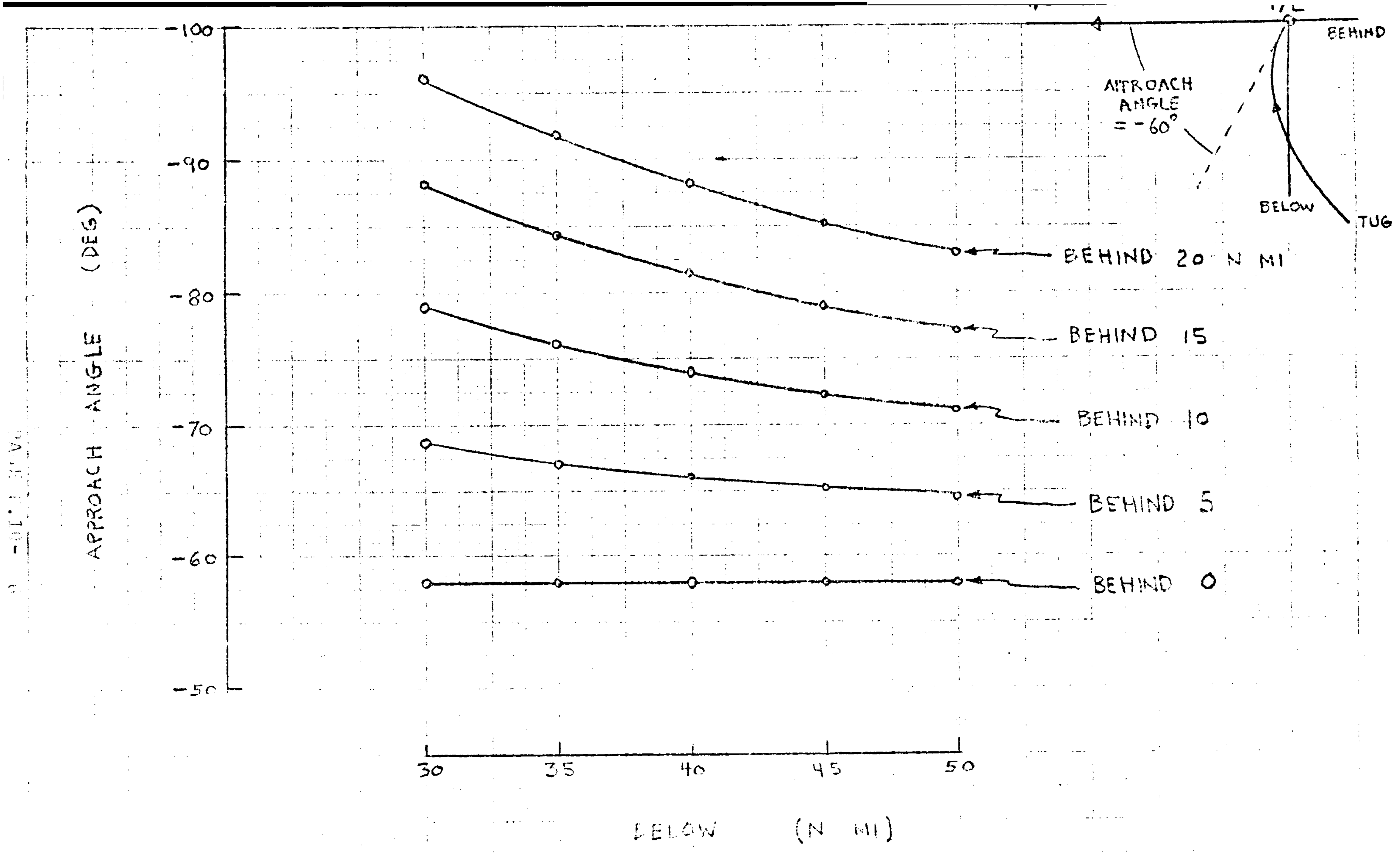


FIG. 2 APPROACH ANGLE VS. TUG INITIAL POSITION RELATIVE TO P/L

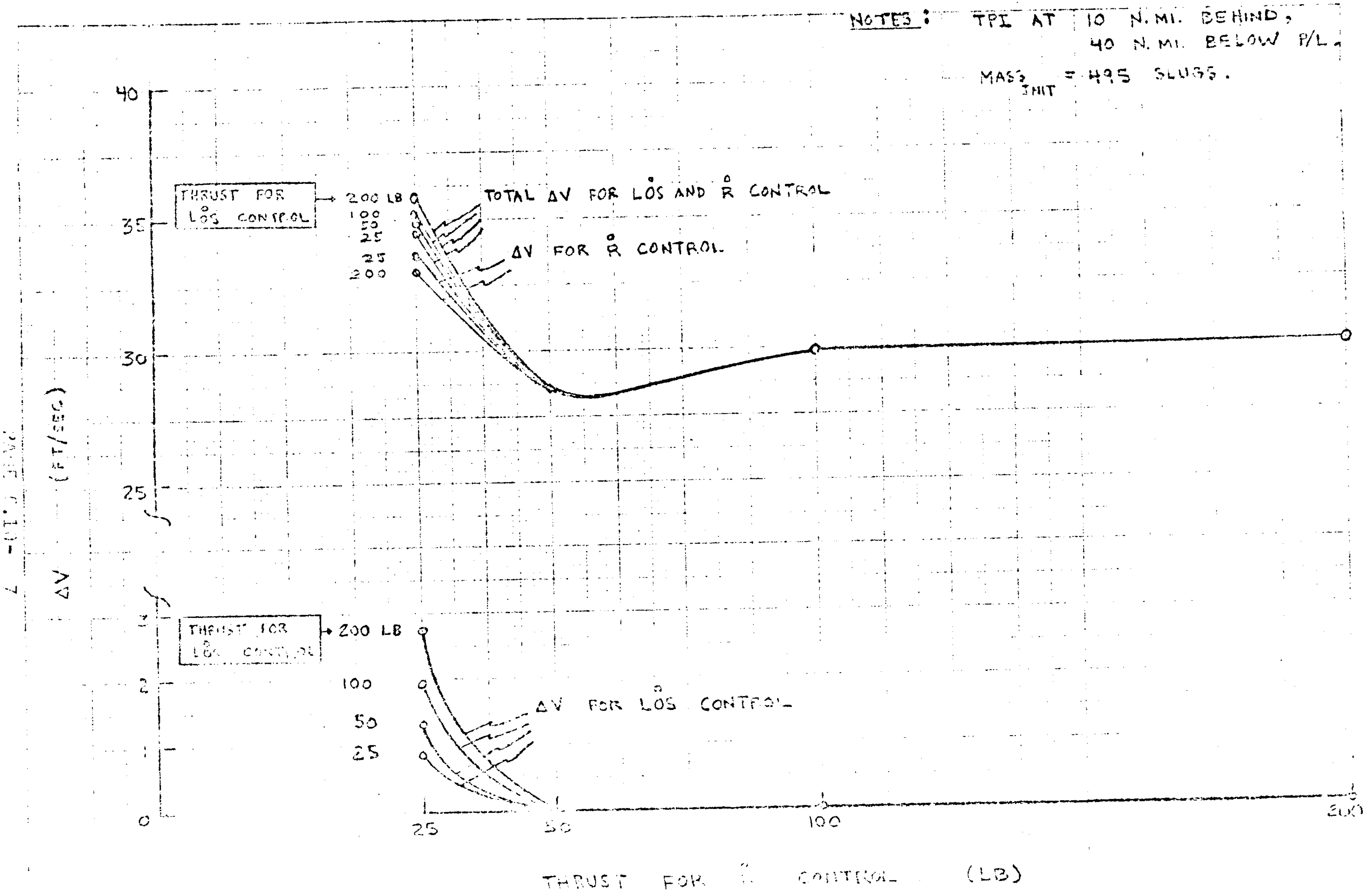


FIG. 3 ΔV FOR TPF VS. APS THRUST LEVELS

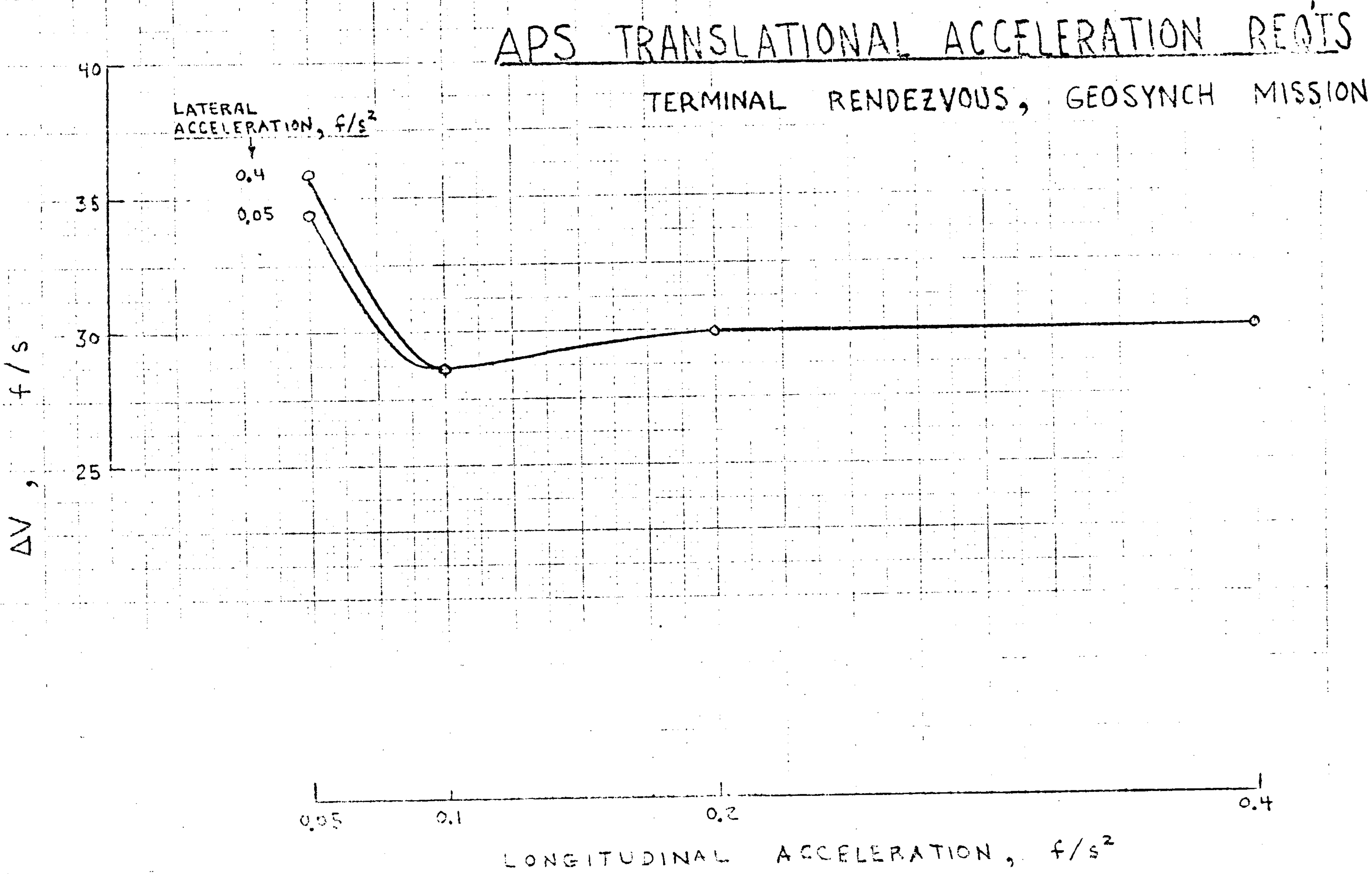


FIG. 4 TPF ΔV VS. TUG ACCELERATION

IMMAN

INTER-OFFICE MEMORANDUM

6.10.2

JECT: RENDEZVOUS WITH PAYLOAD, EFFECTS OF OFF-NOMINAL TPI

NCES:

(1) R. Tellalian,"Guidance Navigation, and Control Subsystem Analysis: Space Tug Rendezvous/Docking Sensor Selection", B82M049-73013, dated 1 May 1973.

(2) G. Zetkov, "Tug Rendezvous with Payload, Delta-V and Approach Angle", B81M049-73018, dated 10 May 1973.

SUMMARY:

Effects of off-nominal conditions just after TPI on rendezvous Delta-V and time duration were computed for a nominal TPI position of 10 n. mi. behind and 40 n. mi. below the target and nominal TPI relative velocity of 40.8 f/s. The following variations were made:

(1) Tug position error of ±5, ±10 n. mi. from nominal, both parallel to the Target Local Vertical and to the direction of target motion and,

(2) Tug velocity error of ±6 f/s in each of the two directions perpendicular to the relative nominal velocity and in the plane of target motion.

For position errors the maximum increase in Delta-V after TPI up to but not including docking was 33 f/s from a nominal of 30 f/s and the maximum increase in time duration was 0.91 hour from a nominal of 2.13 hours. All position error runs were made at 0.2 f/s^2 acceleration level for both LOS rate and range rate control. For velocity errors, the increase in Delta-V was 24 f/s from the nominal of 30 f/s, and the increase in time duration was 0.07 hr. from the nominal of 2.13 hours. These results were obtained for 0.2 f/s^2 acceleration both along and perpendicular to the LOS to the target. Below 0.11 f/s^2 acceleration, rendezvous was not successful, so that on the basis of the runs made, a minimum level of 0.11 f/s^2 is recommended for both LOS rate and range rate control.

INTRODUCTION:

This study is a continuation of the work reported in Reference 2, which basically describes nominal performance. The work reported here is concerned with off-nominal performance. Of major interest are thrust levels - both along the LOS and perpendicular to it - and Delta-V expenditure. Minimum acceleration levels are sought that will result in acceptable performance in terms of target approach, Delta-V expenditure, and time duration.

RANGE GATES:

The range gates were formulated to handle off-nominal trajectories from TPI. The bounds on LOS rate were established by requiring that the velocity transverse to the LOS, as permitted by the tolerance on the LOS rate, would be constrained so that the resulting transverse position deviation from nominal at the next range gate is a fraction of the range at that point. Thus the following formulas were used:

$$V_{T_1} = R_1 \overset{\circ}{L}_1$$

$$e_{p_2} = V_{T_1} \, t \overset{SET}{=} 0.2 \, R_2$$

$$t = \frac{R_1 - R_2}{V_1}$$

Where,

V_{T_1} $\triangleq$ velocity transverse to LOS at Gate 1, deviation from nominal.

R_i $\triangleq$ range at Gate i

$\overset{\circ}{L}_1$ $\triangleq$ LOS rate at Gate 1, tolerance in deviation from nominal

e_{p_2} $\triangleq$ transverse position error from nominal at Gate 2 due to error in LOS rate at Gate 1

t $\triangleq$ time to travel from Gate 1 to Gate 2

V_1 = velocity along LOS at Gate 1

Combining the above formulas:

$$\dot{L}_1 = \frac{\pm 0.2\, R_2 V_1}{R_1(R_1 - R_2)} + \text{Nominal} \quad (1)$$

The LOS rate tolerances used in the runs differ from the formula of Eq. 1 in that the nominal value was not added and, at the shorter ranges, the LOS rate tolerance was not opened up beyond $\pm\, 1.745 \times 10^{-3}$ r/s.

The tolerance as given in Eq. 1 was compared with sensor capabilities. The ITT Scanning Laser Radar error in sensing LOS rate was quoted at 0.05 mr (68). Presently, as stated in Reference 1, it is quoted at 0.1% of LOS rate for 3σ bias and 1% of LOS rate for 3σ random error. The LOS rate tolerances used in the runs are compatible, generally, with the quoted sensor capabilities.

The tolerances on closing velocity were established in the following manner. The nominal closing velocity at the range of the first gate (34 f/s) was used as the nominal closing velocity. A 10% tolerance was permitted around this nominal velocity and about the nominal velocity for each subsequent gate. The nominal velocity at the final gate at R = 300' was selected as 2 f/s. The nominal velocity at the intermediate gates were set between the first and last gate nominal velocity levels such that the size of the velocity decrease in proceeding from the first to the last gates progressively decreases. Thus the nominal velocities were established as follows:

GATE	RANGE, f	NOMINAL CLOSING VELOCITY, f/s	NOMINAL VELOCITY DECREASE FROM LAST GATE, f/s
1	121,000	34	
2	30,400	22	12
3	6,080	13	9
4	1,000	7	6
5	300	2	5

The ranges for the gates were established from the following considerations. The range for the first gate was set at approximately 0.5 of the range at nominal TPI, so that the errors of TPI would be corrected before proceeding too far, with the resulting trajectory not deviating too far from the nominal trajectory. Each subsequent gate range is made a small fraction of the preceeding gate range. Thus the ranges were established as follows:

GATE	RANGE, f	FRACTION OF PRECEEDING RANGE
1	121,600	
2	30,400	0.25
3	6,080	0.20
4	1,000	0.167
5	300	0.30

A small fraction must be used; otherwise the number of gates is too large.

Based on the above considerations, the following gates were used in the runs made:

GATE NO.	RANGE, f	LOS RATE, r/s	RANGE RATE, f/s MIN	RANGE RATE, f/s MAX
1	121,600	$\pm 1.75 \times 10^{-5}$	30.6	37.4
2	30,400	$\pm 7. \times 10^{-5}$	19.8	24.2
3	6,080	$\pm 1.75 \times 10^{-4}$	11.7	14.3
4	1,000	$\pm 1.745 \times 10^{-3}$	6.3	7.7
5	300	$\pm 1.745 \times 10^{-3}$	1.8	2.2

EFFECTS OF INITIAL POSITION ERRORS

The effects on Delta-V of initial position errors relative to the nominal position of 10 n.mi. behind and 40 n. mi. below the P.L. were computed. The position errors were ±5 and ±10 n. mi., with the velocity just after TPI always set at the nominal value. The nominal Tug initial state is:

X	=	119560340.	f
Y	=	69098361.	
Z	=	0.	
X	=	5082.7153	f/s
Y	=	-8723.7612	
Z	=	0.	
MASS	=	495 Slugs	

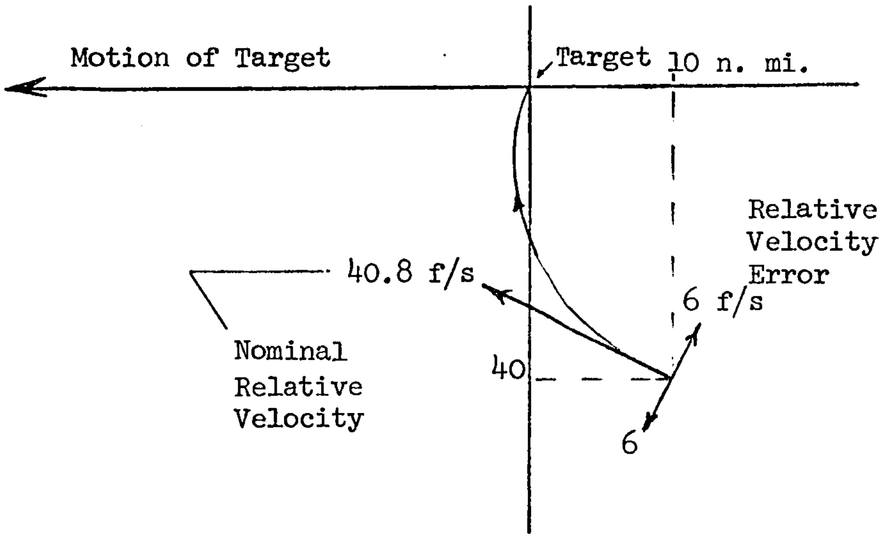
Thus, in effect, the system computes its position as being 10 n. mi. behind and 40 n. mi. below the P.L. and a TPI velocity is generated based on this computation of position, so that when the actual position is not at the nominal position, the TPI velocity generated is not correct for closure to the target. The I_{sp} was set at 230 sec. and the thrust levels for LOS rate and range rate controls were each 100 lb. for all the runs to determine the effects of initial position errors.

The results are shown in Figures 1, 2, and 3. From these Figures, the maximum increase in Delta-V for LOS rate control is 39 f/s. The Delta-V for range rate control actually decreases! The maximum increase in total Delta-V for LOS rate and range rate control is 33 f/s.

The time duration for the maneuver varied from 3.04 hr. (Tug initial position behind 20, below 50 n. mi.) to 1.57 hr. (Tug initial position behind 0, below 30 n. mi.). These two initial positions correspond to the farthest and shortest initial ranges to the target respectively. The nominal time (from 40 behind, 10 below) is 2.13 hr.

EFFECTS OF INITIAL VELOCITY ERROR

The effects on Delta-V of TPI velocity error relative to the nominal TPI velocity were obtained for a nominal position of 10 n.mi. behind, 40 n. mi. below the target. The velocity error was set at 6 f/s in magnitude and pointed perpendicular in the orbit plane to the nominal velocity relative to the target. The nominal velocity relative to the target is 40.8 f/s just after TPI, as shown in the Figure below.



Each of the 2 error velocity vectors was added to the nominal at separate times. Thus, the initial Tug velocity was set as follows:

	VELOCITY (f/s) FOR		
	VELOCITY ERROR DOWN	VELOCITY ERROR UP	NOMINAL VELOCITY
$\dot{X}$ =	5084.5	5080.9	5082.7153
$\dot{Y}$ =	-8729.5	-8718.1	-8723.7612

Initial Mass = 495 Slugs $\quad I_{sp}$ = 230 sec.

The results are shown in Figure 4. With thrust levels = 50 or 25 lb. for both LOS rate and range rate contols, rendezvous was not successful, because the Tug went past the P/L. In addition the Delta-V for these cases begins to climb rapidly. For thrust levels $\cong$ 70 lb. or more for both LOS rate and range rate controls, Delta-V is not significantly changed with variation in thrust level. Improvement in performance could be gained by implementing simultaneous LOS rate and range rate control in the Rendezvous Digital Computer Program, instead of the sequential controls presently implemented. On the basis of the present results, a 55 lb. thrust level is taken as the minimum for both LOS rate and range rate controls. This level corresponds to 0.11 f/s^2 acceleration.

The times were 2.18 hr. (vel. error down) and 2.20 hr. (vel. error up), compared to the nominal time of 2.13 hr.

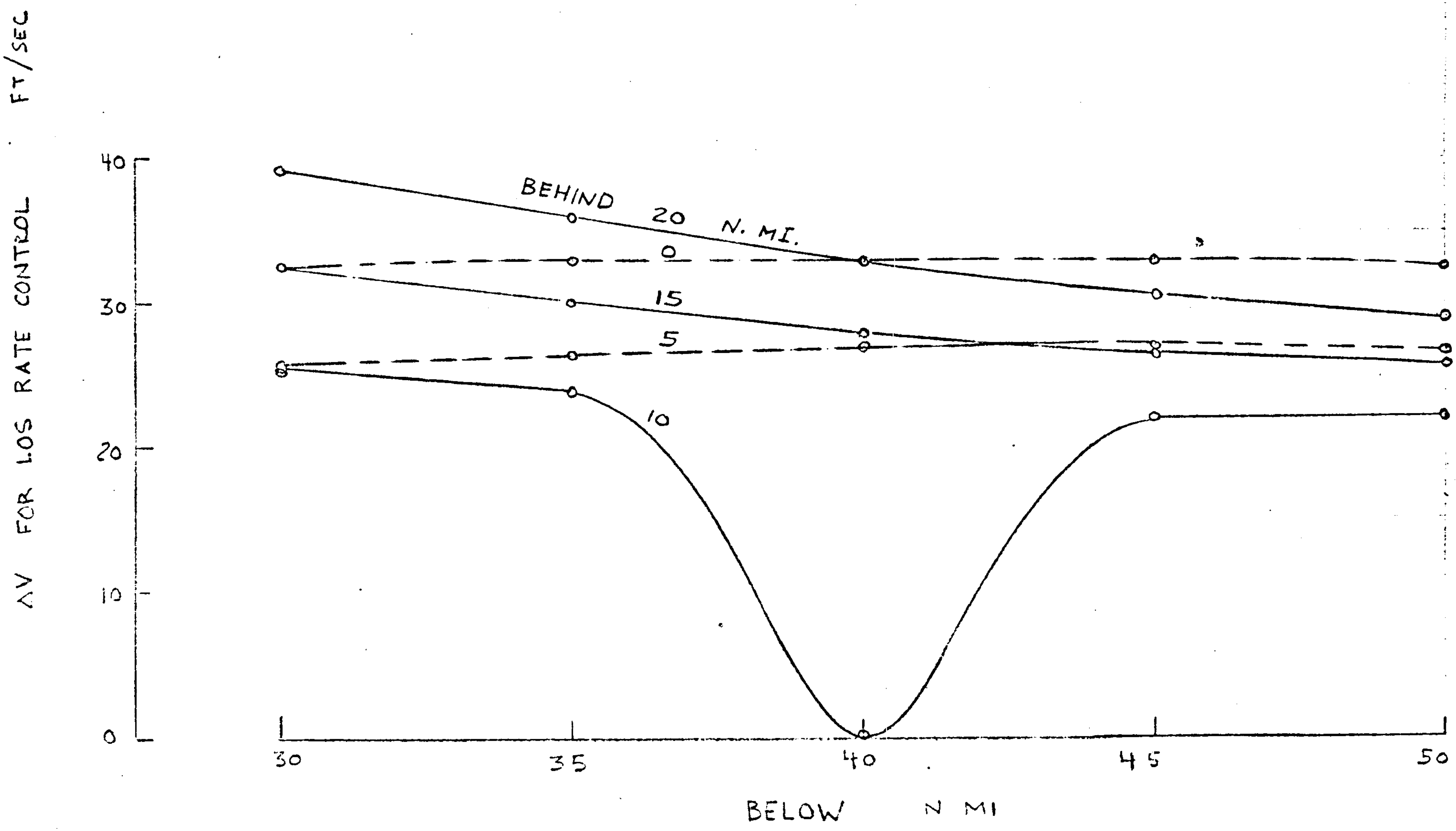


FIG 1 ΔV FOR LOS RATE CONTROL VS. INITIAL TUG POSITION

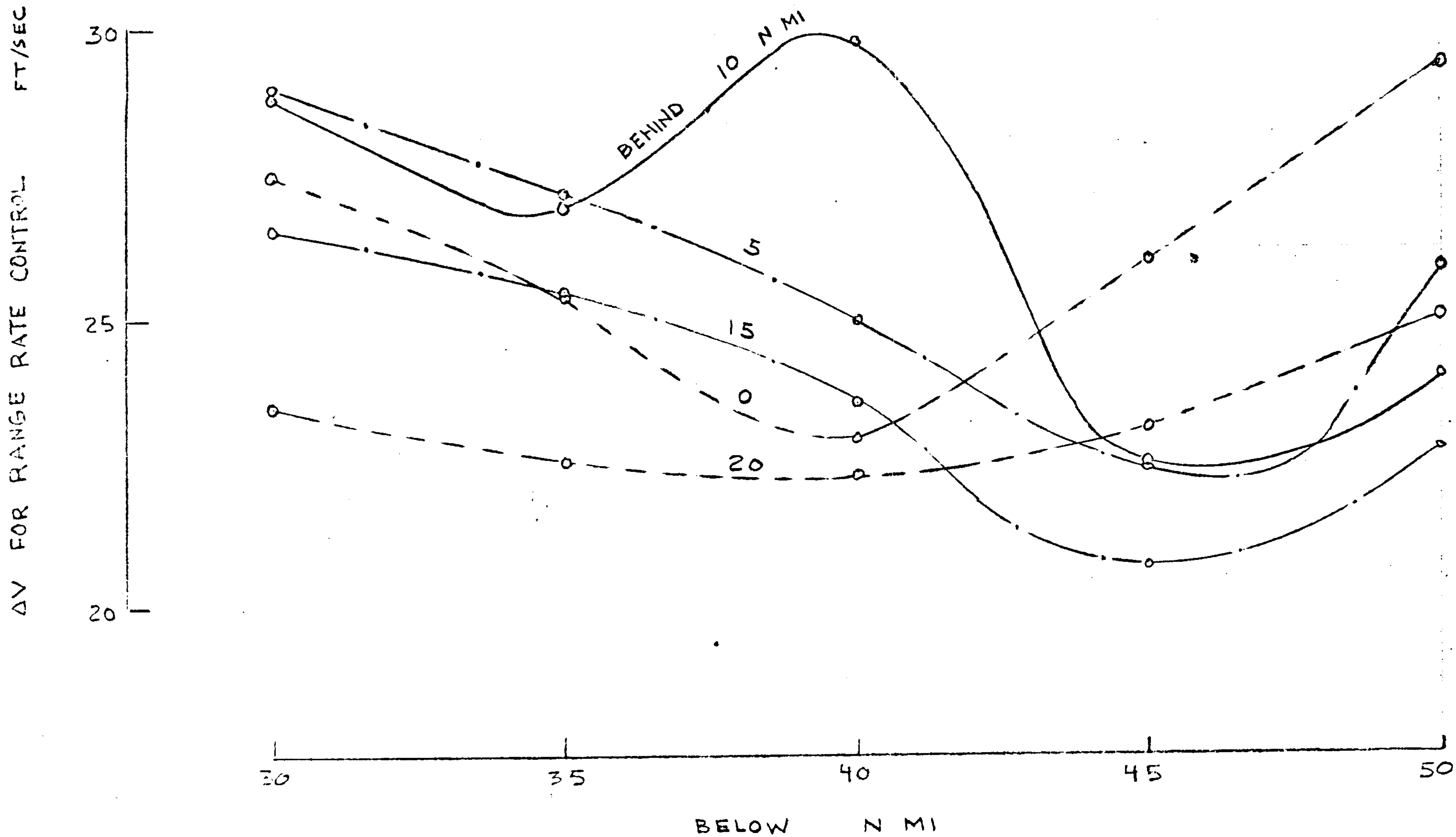


FIG 2 ΔV FOR RANGE RATE CONTROL VS. INITIAL TUG POSITION

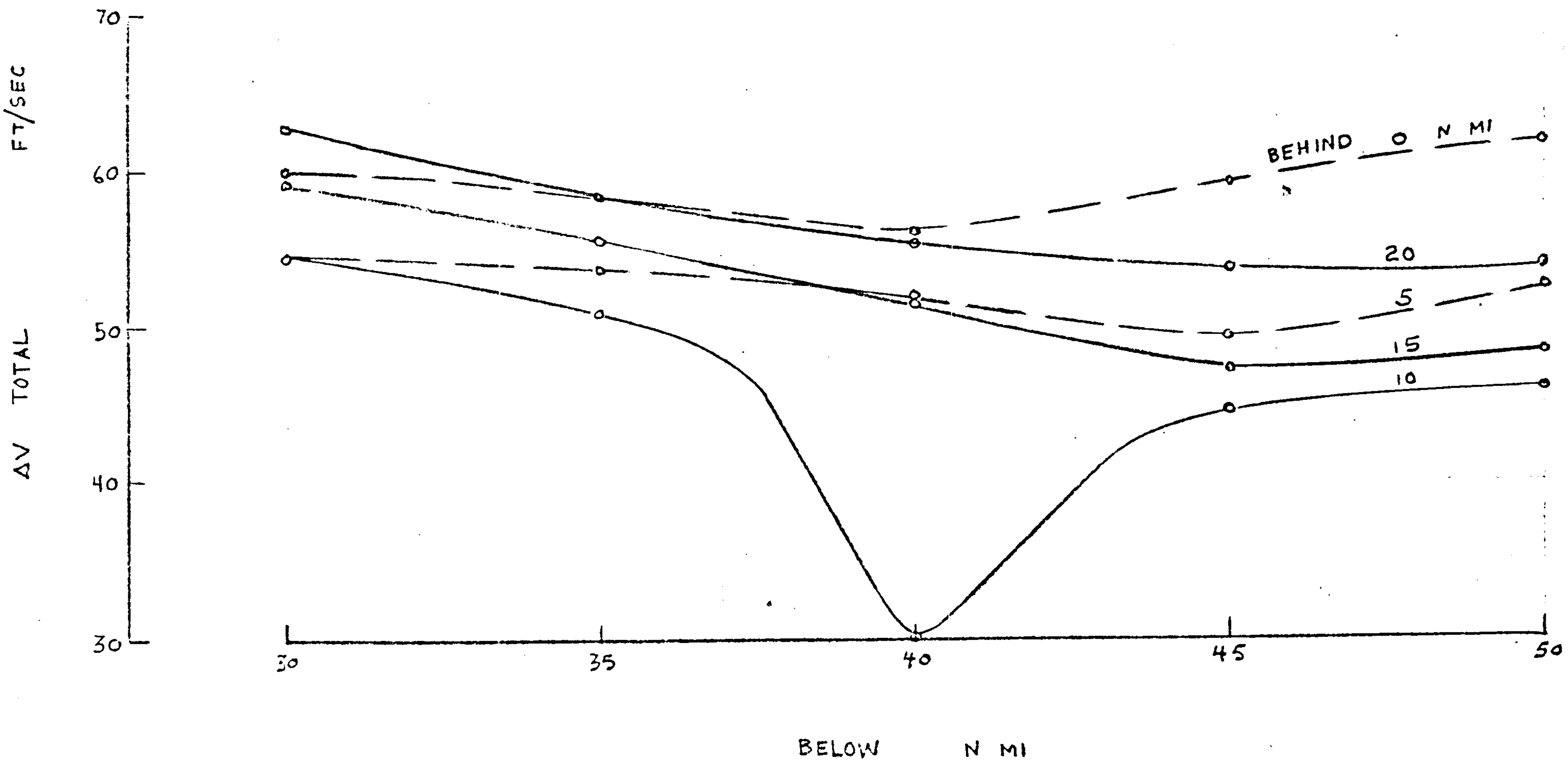


FIG 3 ΔV TOTAL VS. INITIAL TUG POSITION

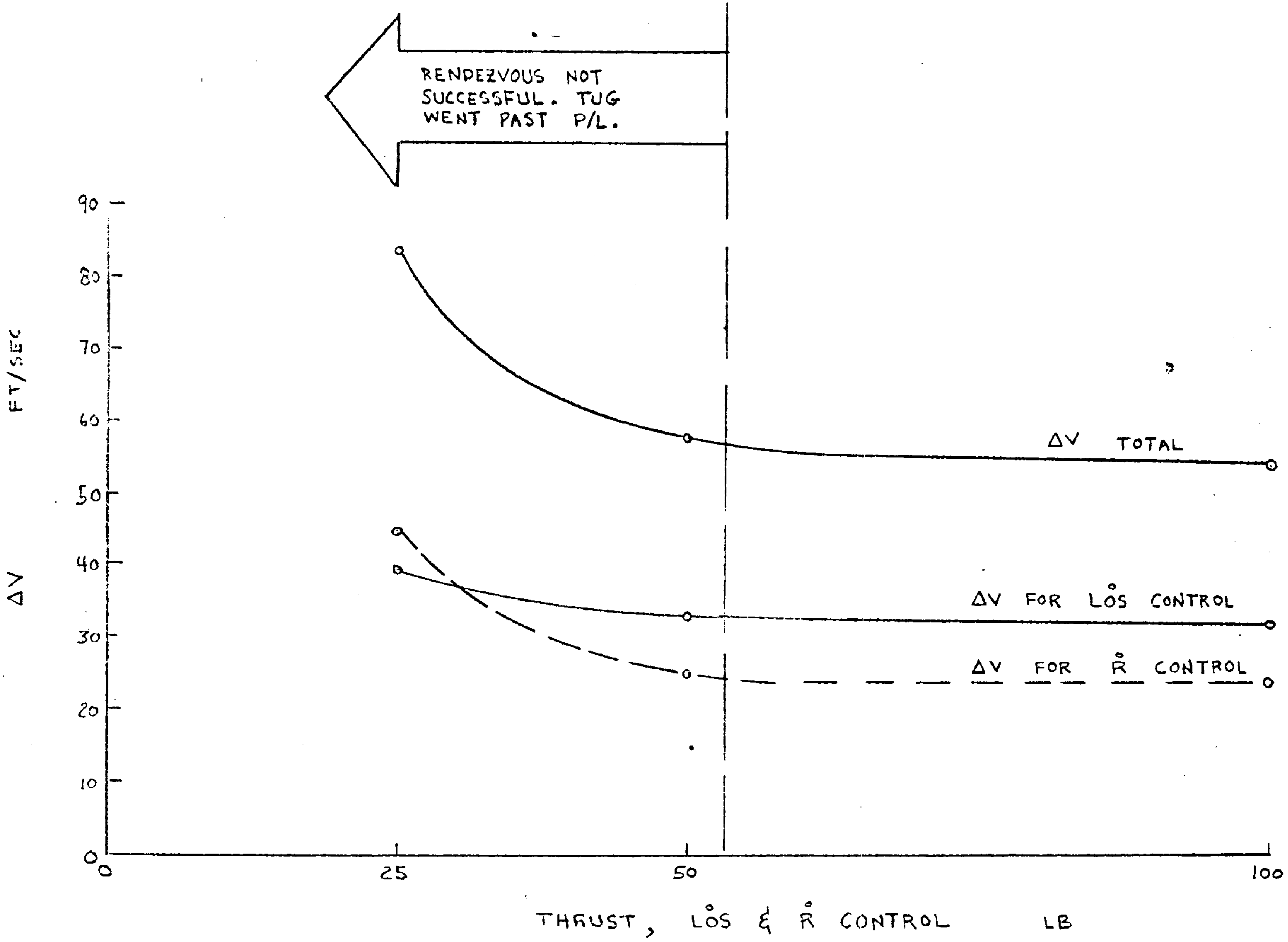


FIG. 4 ΔV VS. THRUST FOR LOS RATE & RANGE RATE CONTROL

IUMMAN

INTER-OFFICE MEMORANDUM

6.10.3

BJECT: DOCKING TO SPACECRAFT WITH SMALL RESIDUAL ANGULAR RATES

RENCES: (1) J. Boudreau, "Apollo Applications Program LM-A/ATM Docking Feasibility Study Summary Report", ARP 250-007 dated 12/20/67.
(2) R. Phagan "Presimulation Report, LM/ATM Docking Feasibility", ARP 250-006, dated 6 December 1967.

SUMMARY:

To determine the significant parameters involved, the conditions required, and the penalties associated with the successful docking of an ST (Space Tug) to a rotating PL (Payload), Grumman work on docking to rotating spacecraft was reviewed. One study was examined in detail; this was an investigation of the manual docking of a LM/ATM (Lunar Module/Apollo Telescope Mount) to an OA (Orbital Assembly, now called Skylab). The results of this study were extrapolated to the case of docking a Space Tug to a rotating PL. Estimates were made of the following:

Maximum PL angular rate and ST time duration and propellant consumption. These estimates were made for manual, remote manual, automatic, and remote automatic types of control, as shown in Table 1 (last page).

NOTE: The docking mechanism requirement that was used for the ST relative angular velocity about the PL docking axis was ±1 d/s (as specified in the Data Package). It is probable that this particular requirement could be significantly increased by the use of a docking mechanism designed to absorb a high rotation rate of the ST about the PL docking axis when the docking axes of the PL and ST are aligned; but the use of such a special docking mechanism was not assumed in this study.

INTRODUCTION:

Grumman work on docking to a spacecraft with small residual spin rates was reviewed. References 1 and 2 are reports of such work, which was done for the Apollo Applications Program in 1967. The FMES (Full Mission Engineering Simulator) was used; the FMES consisted of a visual display having the following:

(1) TV image of an OA mockup with a docking target (shown in Figure 1),

(2) superimposed on the TV image is the COAS (Crewman Optical Alignment Sight) reticle (shown in Figure 1) located in the LM-A (modified LM Ascent Stage).

A qualified pilot operated separate translation and rotation controls and the outputs of these controls were transmitted to computers which simulated jet select logic, the application of jet thrust, and LM-A motion relative to the OA. In turn, a TV camera was translated and oriented relative to the OA mockup to furnish a TV image of the OA to the pilot.

The OA was in a 257 n. mi. circular orbit. The initial range for each run was nominally 85'. The maximum rate command was 4 d/s; the rate DB (dead band) was ±0.25 d/s; and the attitude DB was ±0.3 d. The LM Descent Phase phase-plane control logic was used, with the DAP (digital autopilot) jet select logic corresponding to that of the LM PGNCS (Primary Guidance, Navigation, and Control system). During translation, attitude is held at its last value.

The basic guide to the pilot for docking was as follows:

(1) Null the lateral position (and velocity) errors so that the LM/ATM is on the OA docking axis,

(2) rotate the LM/ATM so that the LM/ATM docking axis is aligned with the OA docking axis,

(3) translate the LM/ATM to the OA.

The docking was terminated when the distance between the docking planes closed to 1.84', at which point the pilot was told that the run was ended. The locations of the docking planes are shown in Figure 2. The LM-A thruster configuration is shown in Figure 3. If the solar arrays on the LM/ATM are in the deployed state, the RCS jet thrust impingement on the solar arrays reduces the +X jet thrust by 50%.

The docking requirements were as follows:

Axial closing velocity	0.1 to 1.0 f/s (1)
Radial velocity	0 to 0.5 f/s
Angular velocity, each axis	±1 d/s
Radial misalignment	0 to 1f
Angular misalignment (including roll)	0 to 10°

The mass properties for the LM/ATM were as follows:
Weight = 28,400 lb./mass = 882.48 slugs
c.m. location X, Y, Z = -6.21, -0.264, -0.157f

I_{xx}, I_{yy}, I_{zz} = 21684.3, 32341.9, 32300.4 sl-ft^2

I_{xy}, I_{xz}, I_{yz} = 942.5, 17.9, 73.2 sl-ft^2
(no sloshing propellant)

Thus the LM/ATM center of mass was 6.21 ft. below the RCS thruster plane, so that for a Y or Z translation, there was an associated rotational disturbance.

(1) In a few runs 0 to 0.1 f/s was required.

PILOT RECOMMENDATIONS:

The following recommendations and comments were made by the two pilots:

(1) There should be an indication at the target that the limit of angular misalignment is exceeded.

(2) There should be an indication when the probe enters the drogue.

(3) Control response is adequate when docking to an inertially stablized OA, but should be improved for docking to a rotating OA.

(4) The effort for docking to a rotating target is demanding; the pilot should be rested before performing this maneuver.

(5) After correcting for off-nominal initial conditions, all runs are the same.

(6) There should be a manual describing operational procedures for specific jet failures.

CONCLUSIONS OF THE REFERENCED STUDY:

(1) Docking a baseline LM/ATM - - i.e., solar arrays stowed and no jet failures - - to an inertially stabilized OA is feasible. The mean time duration is 8 minutes and the mean total impulse expenditure is 12600 lb.- sec. (45 lb. for I_{sp}=281 sec.)

(2) Docking a baseline LM/ATM to an OA rotating at 0.1 d/s about all 3 axes simultaneously is feasible. Some dockings were unsuccessful. The mean time duration is 8 minutes and the mean total impulse expenditure is 25,300 lb. - sec. (90 lb. for I_{sp}=281 sec.)

(3) Docking a baseline LM/ATM to an OA rotating at 0.3 d/s about all 3 axes simultaneously was not demonstrated to be feasible. One-half of the attempts were unsuccessful. The most difficult task was to attain terminal angular rates below the specified limit of 1 d/s.

(4) The requirement to close at a velocity between 0 and 0.1 f/s rather than 0.1 and 1 f/s, makes docking more difficult. For example, docking a baseline LM/ATM to an OA rotating at 0.3 d/s about all 3 axes simultaneously could not be accomplished.

(5) The flexible solar arrays, if deployed on the LM/ATM, oscillated severely as the docking approach was made. Docking with solar arrays deployed was not demonstrated to be feasible.

(6) There is a rotational disturbance during Y or Z translation because the center of mass is 6.21 ft. below the RCS thruster plane. The effect of this disturbance on the pilot is to generate errors in his estimates of translational position and velocity. Change in control logic could be made to reduce the rotation resulting from Y or Z translation.

EXTRAPOLATIONS BASED ON THE RESULTS OF THE REFERENCED STUDY

Reliable docking to the OA could not be accomplished by the baseline LM/ATM, when the OA rotated at 0.3 d/s or higher about all 3 axes simultaneously). It is desired to extrapolate this result to a statement on maximum rotational rates of the P.L. for which successful docking by the Space Tug is possible. There are numerous parameters involved in the process of docking, and there can be different parameter sets for different docking systems. For example, docking performance is sensitive to the following parameters:

(1) Contact requirements imposed by docking mechanism.

- Translation:
  - ~ lateral misalignment
  - ~ longitudinal and lateral velocities
- Rotation:
  - ~ angular misalignments
  - ~ angular velocities

(2) Location of docking hatch relative to the center of mass: chased and chaser spacecraft.

(3) Rotational motion of chased spacecraft (active pointing of target spacecraft spin axis toward chaser not assumed).

- ~ angular rate vector: fixed or moving relative to chased spacecraft coordinate frame (the angular rate vector was fixed in the OA coordinates of the referenced study).

(4) Sensor:

- Pilot's image of target on chased spacecraft and image of chased spacecraft.
  - ~ eye view through window, as affected by location of eye. (nominal plus variation)
  - ~ TV image, as affected by time delay, sharpness of image, location of TV camera.
  - ~ reticle size and pattern, superimposed on image of target on chased spacecraft.
  - ~ target size and pattern mounted on chased spacecraft.
- Optical scanner view of reflector array on target spacecraft.

(5) Control logic.

- Sequential operation of manual controls, translation and rotation; sequential operation of each axis in translation and in rotation.
- Automatic parallel operation of translation and rotation controls.
- Automatic control logic uses knowledge of rotational disturbance generated during application of translation forces to prevent rotations before they occur.
- Dead band values, positions and velocities, for translations and rotations.

(6) Forces and torques produced by control jets.

(7) Mass properties.

- Total mass.
- Location of center of mass.
- Inertias.
- Propellant slosh.
- Bending: appendages, or connections between major elements.
- Crew Motion.

In the case in which the types of parameters remain the same between docking systems, each of the parameter values must be known for the LM/ATM/OA and the ST/PL, and the sensitivities to the variations in the parameter values from the values used in the base set (LM/ATM/OA) must be known. In the following sections, estimates are made of these sensitivities, and based on the estimated sensitivities, extrapolations are made from the manual docking of (LM/ATM)/OA to the manual, remote manual, automatic, and remote automatic docking of ST/PL.

1. Extrapolation from Manual (LM/ATM)/OA Docking (No Time Delay) to Manual ST/PL Docking (No Time Delay)

The following formula relates the maximum rate of the OA for which the LM/ATM can dock to the OA to the maximum rate of a PL for which the ST can dock to the PL:

$$\omega_{MAX_{PL}} = \left[\frac{d_{LM/ATM}}{d_{ST}} \times \frac{d_{OA}}{d_{PL}} \times \frac{\ddot{X}_{ST}}{\ddot{X}_{LM/ATM}} \times \frac{\ddot{\theta}_{X\,ST}}{\ddot{\theta}_{X_{LM/ATM}}} \right] \omega_{MAX_{OA}}$$

where ω = angular rate simultaneously about each of 3 axes

d = distance, docking mechanism to center of mass

$\ddot{X}$ = maximum possible translational acceleration along X axis

$\ddot{\theta}_X$ = maximum possible angular accleration about X axis

The above formula neglects differences in contact requirements, target spacecraft wobble, view of target, processing of sensed information, sloshing, bending, and crew motion. Contact requirements will be considered shortly.

For the following values,

d_{ST}	=	6',	$d_{LM/ATM}$	=	15.8'
d_{PL}	=	6',	d_{OA}	=	39.1'
$\ddot{X}_{ST}$	=	0.4 f/s^2,	$\ddot{X}_{LM/ATM}$	=	0.45 f/s^2 (4 jets, not incl. impinge.)
$\ddot{\theta}_{X_{ST}}$	=	5 d/s^2	$\ddot{\theta}_{X_{LM/ATM}}$	=	5.4 d/s^2 (4 jets, not incl. impinge.)

then

$$\omega_{MAX_{PL}} = \left[\frac{15.8}{6} \times \frac{39.1}{6} \times \frac{0.4}{0.45} \times \frac{5}{5.4} \right] 0.1 = 14(0.1) = 1.4 \text{ d/s}$$

before consideration of contact requirements.

The effect of differences in contact requirements is now estimated. Contact requirements for (LM/ATM)/OA and ST/PL are compared in the following table:

PARAMETER	(LM/ATM)/OA	ST/PL
Misalignment:		
Radial (d_{radial})	±1 f	±0.5 f
Angular (θ)	±10 deg	±3 deg
Relative Velocity:		
Longitudinal (V_{long})	0.1 to 1 f/s	0.1 to 1 f/s
Radial (V_{radial})	0.5 f/s	0.3 f/s
Angular ($\dot{\theta}$)	±1 deg/s	±2.4 deg/s

Weighting angular velocity more heavily because pilots found difficulty in satisfying this requirement, the following formula is used to obtain the advantage factor at contact for (ST/PL)/((LM/ATM)/OA):

$$f = \frac{d_{radial}}{d_{radial}} \times \frac{\theta}{\theta} \times \frac{V_{long}}{V_{long}} \times \frac{V_{radial}}{V_{radial}} \times \left[\frac{\dot{\theta}}{\dot{\theta}} \right]^2 \begin{matrix} \text{ST/PL} \\ \text{(LM/ATM)/OA} \end{matrix}$$

Thus the factor is

$$f = \frac{0.5}{1} \times \frac{3}{10} \times \frac{1}{1} \times \frac{0.3}{0.5} \times \left(\frac{2.4}{1}\right)^2 = 0.5,$$

the requirements for ST/PL being more difficult overall. Multiplying $\omega_{MAX_{PL}}$ = 1.4 d/s, as calculated previously, by 0.5 to account for differences in contact requirements,

$$\omega_{MAX_{PL}} = 0.7 \text{ d/s}$$

Thus, for the assumed case, 0.7 d/s is the estimate for the maximum angular rate of the PL simultaneously about each of its 3 axes for which the ST can be manually docked to the PL.

The time duration is basically a function of the translation velocity profile. The velocity profile in turn is influenced by the translation acceleration, if the translation acceleration capability is not sufficient to develop the desired velocity profile. Thus the estimation for time duration is the following:

$$t_{T_{ST}} = \left(\frac{\ddot{X}_{LM/ATM}}{\ddot{X}_{ST}} \right)^{0.333} t_{T_{LM/ATM}}$$

$$= \left(\frac{0.45}{0.4} \right)^{0.333} (8 \text{ Minutes})$$

$$= (1.04)8 = 8.3 \text{ Minutes}$$

Propellant is nominally needed most for translation and least for rotation. The translation impulse, for constant mass, is m ΔV. With the same velocity profile, Delta-V is the same, so that the propellant consumption is proportional to mass. Thus the ST propellant consumption is estimated to be

$$\rho_{ST} = (m_{ST}/m_{LM/ATM})\, \rho_{LM/ATM}$$

$$= \frac{490}{882} \times 25300 \text{ lb.-sec.} = 14000 \text{ lb.-sec.}$$

(61 lb. at I_{sp} = 230)

2. Extrapolation From Manual Operation (No Time Delay) to Remote Manual Operation (With Time Delay)

The effect of time delay is implicit in the following formulas:

$$t_T \text{ with } t_d = t_T \text{ with no } t_d$$

$$\rho \text{ with } t_d = \rho \text{ with no } t_d$$

$$\omega_{max_{with_{t_d}}} = \left[1/(1+t_d)\right] \omega_{max_{no_{t_d}}}$$

where t_T = time duration of docking run

t_d = time delay

ρ = propellant impulse

The total time delay (transmission and processing) for Remote ST/PL docking is estimated to be 1 second or less:

Substituting t_d = 1 sec. into the above expressions and using ST manual operation as a base,

t_T = 1 (8.3) = 8.3 minutes

ρ = 1 (14,000) = 14,000 lb.-sec.

ω_{max} = 0.5 (0.7) = 0.35 d/s

3. Extrapolation From Manual Operation (No Time Delay) to Automatic Operation (No Time Delay)

The pilot has a tendancy to operate in a sequential manner, concentrating on one task at a time, such as controlling one axis in translation, then another axis in translation, then about an axis of rotation and so on. Automatic operation, on the other hand, can proceed in a parallel manner with all 6 degrees of freedom (3 translation, 3 rotation) being controlled simultaneously.

Just before contact, it is assumed that 6 degree-of-freedom parallel operation as could be performed by automatic control is required whereas it is assumed that the pilot can effectively operate no more than 2 degrees of freedom in parallel. The advantage of automatic vs. manual control just before contact is thus taken as a factor of 3. Referring to the case above in which the estimate for the maximum PL angular rate for manual docking is 0.7 d/s, the same estimate for automatic docking is 3 (0.7) = 2.1 d/s.

Assuming that (1) when the need arises, the pilot effectively controls a maximum of 2 degrees of freedom (in comparison with the 6 degrees of freedom controlled in automatic operation) and (2) the need for 6 degree-of-freedom control occurs approximately one-tenth of the time, then the advantage over the entire maneuver of automatic over manual is $\frac{6}{2} \times \frac{1}{10} + 1 \times \frac{9}{10} = 1.2$.
This advantage is applied not only to time duration but also to propellant use, because less propellant is required when performing simultaneous translation (more than one axis) and simultaneous translation and rotation maneuvers. Thus the estimates for automatic operation are 1/1.2 = 0.84 of the time duration and propellant consumption required for manual operation. The estimate for mean time is then 0.84 x 8.3 = 7 minutes and the estimate for mean propellant is 0.84 x 14,000 = 11800 lb.-sec. (51. lb. at I_{sp} = 230).

4. <u>Extrapolation From Automatic Operation (No Time Delay) to Remote Automatic Operation (With Time Delay)</u>

The concept of automatically processing signals that are transmitted from the ST to the ground (no man-in-the-loop) and then transmitting the automatically processed signals to the ST is now considered. Applying the effects of time delay as estimated previously to the estimates made previously for automatic control (no time delay), the estimates for remote automatic control (with 1 second time delay) are as follows:

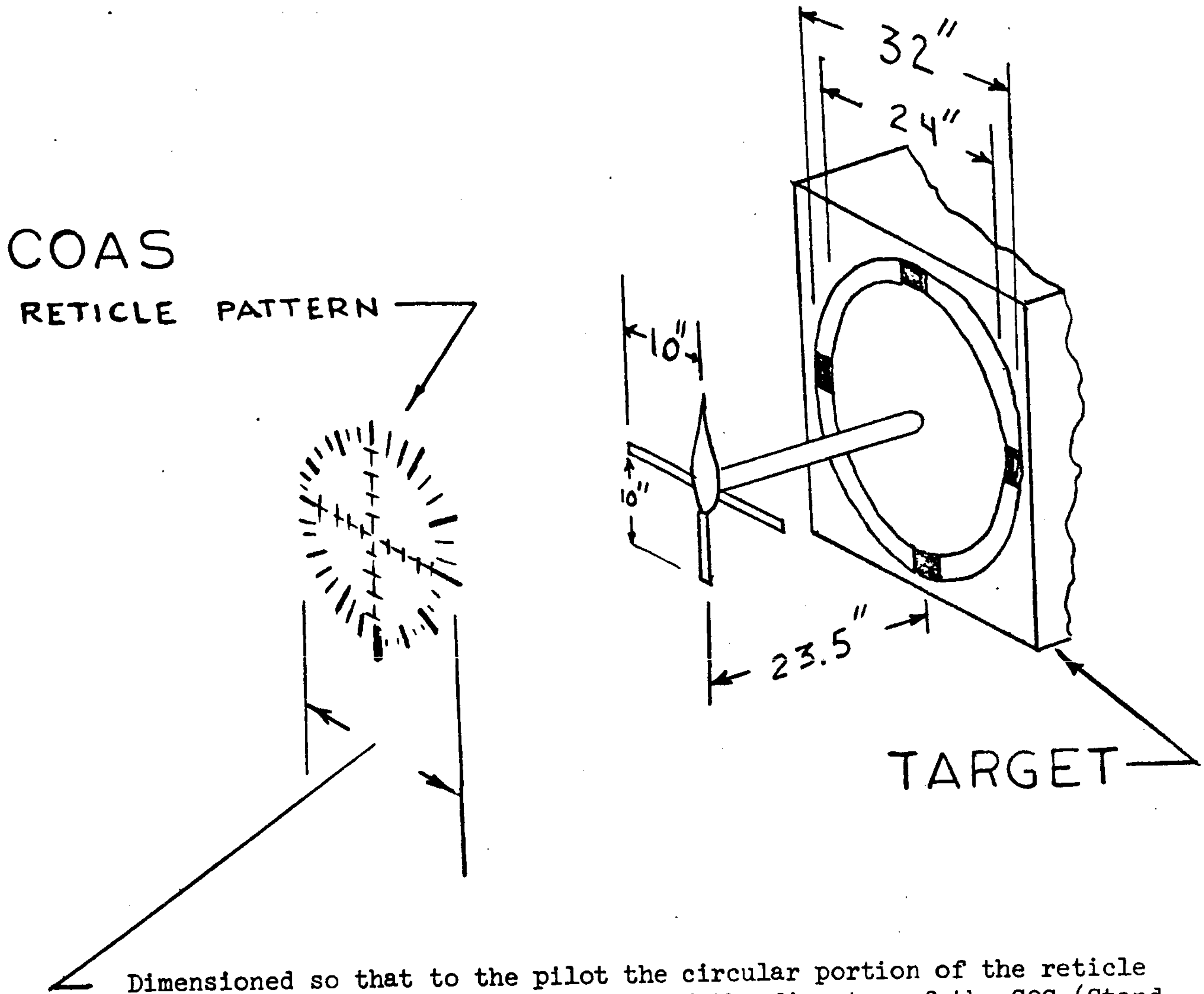
$t_d = (1)(7) = 7$ minutes

$\rho = (1)(11800) = 11800$ lb.sec.

$\omega_{max_{PL}} = 0.5\,(2.1) = 1.05$ d/s.

5. Summary of Extrapolations

The previous extrapolations that were made are summarized in Table 1. Sloshing propellant effects are not included; it is expected that sloshing propellant would degrade the performance estimates of Table 1.



Dimensioned so that to the pilot the circular portion of the reticle pattern appears to enclose one-half of the diameter of the SOC (Stand-off Cross) on the OA Target, when the LM/ATM is docked.

FIGURE I

CREWMAN OPTICAL ALIGNMENT SIGHT AND TARGET FOR DOCKING

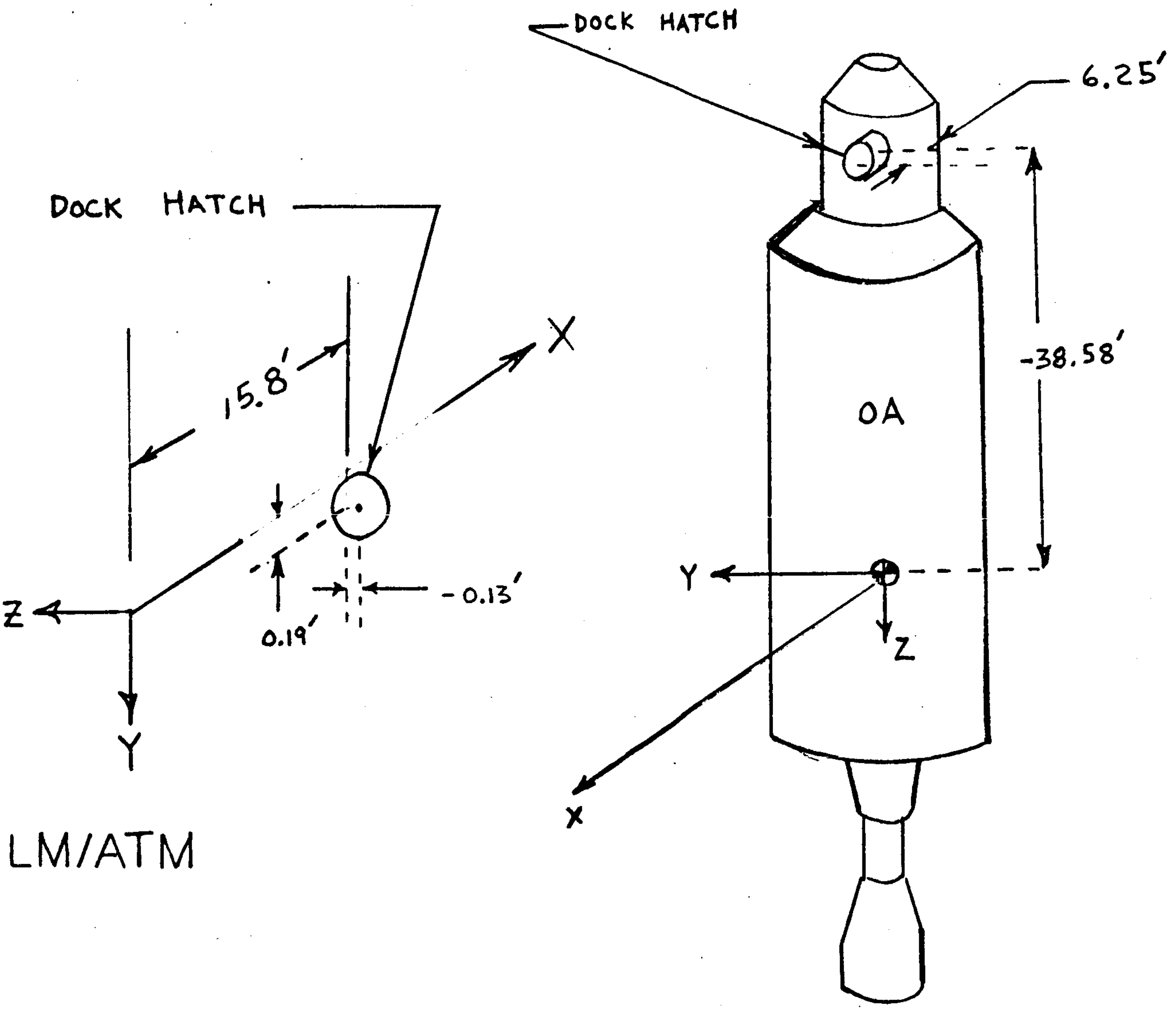


FIGURE 2

LOCATIONS OF DOCKING HATCHES ON LM/ATM AND OA

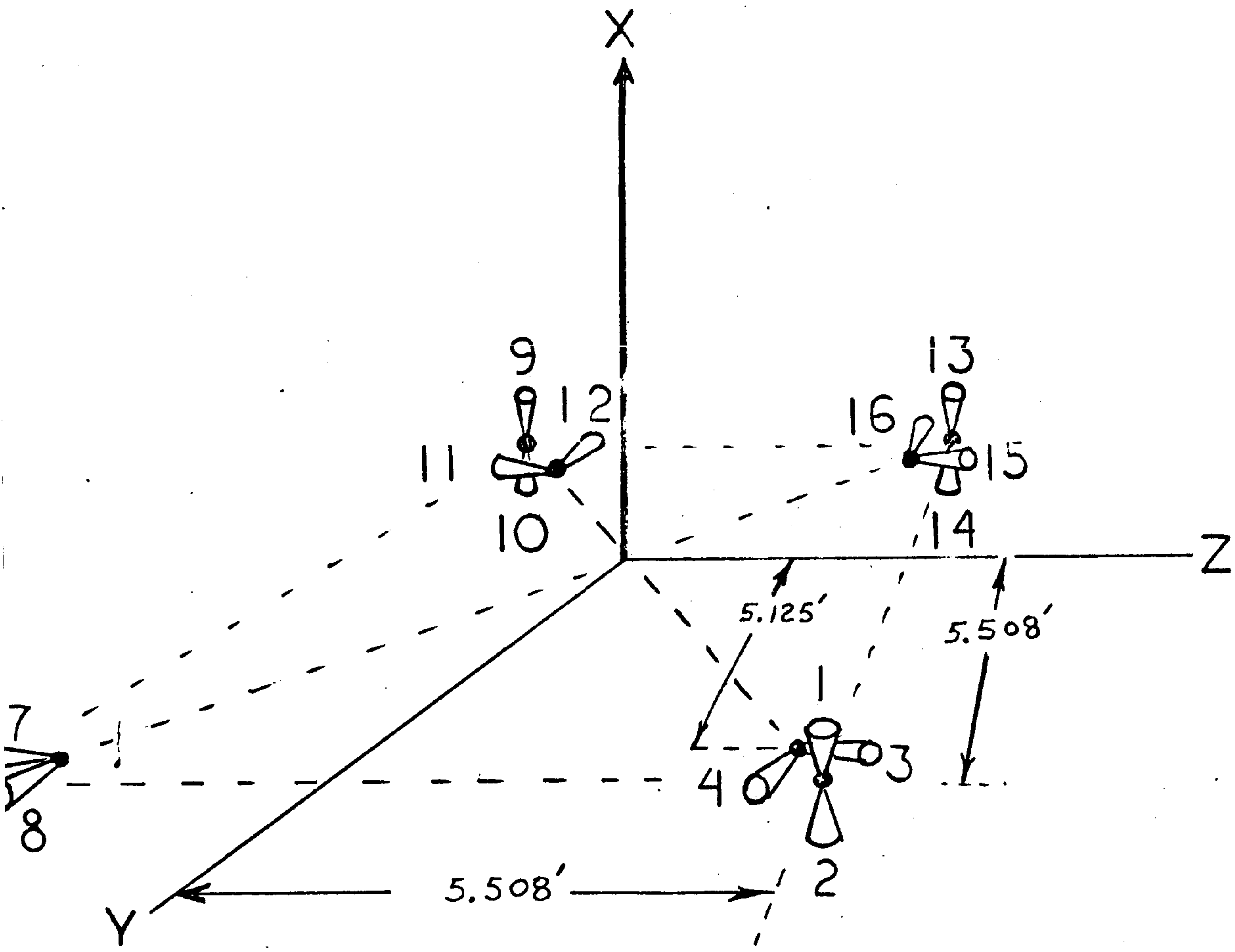


FIGURE 3

LOCATIONS OF JETS ON LM/ATM IN YZ REFERENCE AXES PLANE

TABLE I

SUMMARY OF PERFORMANCE ESTIMATES FOR SPACE TUG/PAYLOAD DOCKING, BASED ON STUDIES OF MANUAL (LM/ATM)/OA DOCKING

SPACE TUG/PAYLOAD	TYPE OF DOCKING			
PARAMETER	MANUAL	REMOTE MANUAL (TIME DELAY = 1 SEC)	AUTOMATIC	REMOTE AUTOMATIC (TIME DELAY = 1 SEC)
MAX ANGULAR RATE OF PL, EACH OF 3 AXES, FOR WHICH ST CAN DOCK TO PL (d/s)	0.7	0.35	2.1	1.05
TIME DURATION TO DOCK FROM R = 85' (MINUTES)	8.3	8.3	7.0	7.0
PROPELLANT TO DOCK FROM R = 85' (LB. - SEC.)	14000 (61 lb)	14000	11800 (51 lb)	11800

EXTRAPOLATED FROM

(LM/ATM)/OA
TYPE OF DOCKING
MANUAL
0.1
8
25300

SPACE TUG:

I_{sp} = 230 SEC.

dist, cm to dock mech = 6'

$\ddot{X}_{max}$ = 0.4 f/s^2

$\ddot{\theta}_{X_{max}}$ = 5 d/s^2

M = 490 SLUGS

PAYLOAD:

dist, cm to dock mech = 6'

CONTACT REQUIREMENTS

Misalignment: Radial ±0.5f; Angular ±3d

Velocity: Axial 0.1 to 1 f/s; Radial 0.3 f/s; Angular ±2.4 d/s

LM/ATM:

I_{sp} = 281 SEC.

dist, cm to dock mech = 15.8'

$\ddot{X}_{max}$ = 0.45 f/s^2

$\ddot{\theta}_{X_{max}}$ = 5.4 d/s^2

M = 882 Slugs

ORBITAL ASSEMBLY

dist, cm to dock mech = 39.1'

CONTACT REQUIREMENTS

Misalign: Radial ±1 f; Angular ±10d

Velocity: Axial 0.1 to 1 f/s; Radial 0.5 f/s; Angular ± 1 d/s

GRUMMAN

INTER-OFFICE MEMORANDUM

6.10.4

SUBJECT: RENDEZVOUS, STATIONKEEPING, AND DOCKING TO NONROTATING SPACECRAFT

References: (1) J. Boudreau, "Simulation Report for LM/ATM Remote Control Simulation", ARP250-009, dated June 15, 1970.

(2) E. Sommer, G. Steinman, "Presimulation Report for LM/ATM Remote Control Simulations", ARP250-008, dated January 2, 1969.

(3) G. Zetkov, "Docking to Spacecraft with Small Residual Angular Rates", B81M049-73030, dated 22 June 1973.

Summary:

To determine the conditions required and penalties for the successful docking of an ST (Space Tug) to a nonrotating PL (Payload), Grumman work on remote manual docking was reviewed. One study was examined in detail; in this study, a pilot in an OA (orbit Assembly, now called Skylab) remotely controlled a LM/ATM (Lunar Module/Apollo Telescope Mount) to dock the LM/ATM to the OA. Based on these results, extrapolations are made to the ST/PL case with performance estimates being made for the following: docking, stationkeeping, and rendezvous by manual, remote manual, automatic, and remote automatic types of control.

Introduction:

Grumman work on remote man-in-the-loop rendezvous, stationkeeping, and docking to a nonrotating spacecraft was reviewed. (This review is similar to the review reported in Ref. 3; the rationale for the estimation process is more fully explained in Ref. 3). References 1 and 2 are reports of this work, which was done for the Apollo Applications Program in 1969.

A simulator was used in which a qualified pilot, located in a mockup of the OA crew station, operated separate translation + rotation controls, the outputs of the controls being transmitted to all-analog computers which simulated (1) transmission & processing time delay involved in radioing the control signals to the LM/ATM, (2) Jet select logic, (3) application of jet thrust, (4) motion of the LM/ATM relative to the OA, and (5) translation and rotation commands to a TV camer pointed at a mockup of the LM/ATM. The TV image of the mockup was shown to the pilot; in the actual case, the pilot would see the LM/ATM directly. The simulator consisted of the following:

(1) Visual Display: TV image of LM/ATM mockup. Mockup scale: 1/20 for ranges 0 to 70' and 1/250 for ranges 100 to 1000'. An Apollo type target was mounted on the LM/ATM mockup.

(2) Crew Station: Mockup of station in MDA (Multiple Docking Adaptor) of the OA. The window had a 60°x80° FOV. The COAS (Crewman Optical Alignment Sight) reticle was in the center of the window. A qualified pilot operated hand controllers: Left - LM/ATM translation, right - LM/ATM rotation.

(3) Command Link: A pure time delay was used with a nominal value of 0.4 second to simulate the delay between the translation or attitude command and LM/ATM jet actuation.

The OA was fixed in the orbit reference axes system (x: direction of OA motion, Z: towards Earth along LV). The attitude control system used for the LM/ATM was the LM Abort Control System, consisting of the ATCA (Attitude + Translation Control Assembly), the RGA (Rate Gyro Assembly), and, for attitude hold, the AGS (Abort Guidance System). The attitude deadband was 0.3°, and the rate deadband was 0.2°/S. In attitude hold, the LM/ATM was held fixed with respect to the orbit reference axis system. Each jet thrust was 100 lb. For x axis translation only, 4 jets are used; for y or z translation only, 2 jets are used. For rotations about x,y, or z axis only, 4 jets are used. The nominal initial separation between the docking ports was 50'.

The mass properties for the LM/ATM were set as follows:

Weight/mass = 28200 lb/876 slugs

cm location x,y,z =-6.5, -0.2, -0.1 ft

I_{xx}, I_{yy}, I_{zz} = 21300, 40900, 39400 sl-ft^2

I_{xy}, I_{xz}, I_{yz} =-210, 290, 40 sl-ft^2

(no sloshing propellant)

A fly-to, rather than fly-from, approach was used by each of the 3 pilots; i.e., the pilot moved his controls as if he were flying the OA to the LM/ATM (while the opposite is true). The TCA (Tranlation Controller Assembly) and the ACA (Attitude Controller Assembly) were operated one axis at a time (all pilots). The TCA was normally pushed bang-bang, except when correcting large translation rates.

Results of the Referenced Study

The study (ref. 1) investigated docking, stationkeeping, transition from final braking to stationkeeping, and rendezvous . The nominal configuration consisted of the following: time delay = 0.4 sec, the attitude hold is in effect when rate commands are not being applied, the attitude deadband = 0.3°, the angular rate command, maximum = 1 d/s, and the rate deadband = 0.2 d/s. The conclusions of the study are summarized below.

---

1. Docking

1.1 Nominal remote manual docking of the LM/ATM was easy. The mean time duration was 3 minutes and the mean propellant consumption was 7030 lb-sec (25 lb at I_{sp} = 281 sec.).

1.2 Remote manual docking of the LM/ATM without the use of attitude hold was successful, with the performance degraded from nominal operation. Increasing the maximum rate command from 1 to 2 d/s slightly degraded performance, and reducing the rate deadband from 0.2 to 0.1 d/s improved performance.

1.3 The upper limit on time delay was 1 second for acceptable remote manual docking of the LM/ATM to the OA.

2. Stationkeeping

2.1 The optimum range for remote stationkeeping of the LM/ATM relative to the OA by a pilot in the OA was 50' to 150'. This corresponds to a 10 to 15° half-cone-angle through the OA window(the pilot stationkeeps by keeping the LM/ATM in the window and at a desired range). The propellant for R=50' to 150' was 92.6 to 197 lb-sec/min (0.33 to 0.7 lb/min at I_{sp} = 281 sec). With attitude hold, there is a low level of pilot participation. Without attitude hold, stationkeeping is impractical for more than 3 or 4 minutes.

3. Transition from Region of Final Braking to Region of Stationkeeping

3.1 Transitioning from the final braking range (500') to the stationkeeping range (120') required a mean time of 6.2 minutes and a mean propellant of 17400 lb-sec (62 lb at I_{sp} = 281 sec).

3.2 Attitude could not be estimated at ranges larger than 300 feet. Without attitude hold, the rate deadband had to be decreased from 0.2 to 0.1 d/s, so that the rate of attitude buildup was slower.

4. Rendezvous

4.1 Initially the LM/ATM was set at a range of 900' above the OA (along the LV) with a closing velocity of 10 f/s. The pilot in the OA remotely maneuvered the LM/ATM to a range of 500' or directly to a range of, 120'. In going to a range of 120', the mean propellant was 31800 lb-sec (113 lb at Isp = 281 sec) and the mean time was 2.7 minutes.

Extrapolations Based on the Results of the Referenced Study

Based on the results of the referenced study on the remote manual control of LM/ATM to the OA, estimates are now generated for the performance of maneuvering a ST to a PL. The techniques used for extrapolation are basically the same as those used in Ref. 3.

1. Extrapolation from (LM/ATM)/OA Remote Manual Docking, Stationkeeping, & Rendezvous (Time Delay = 0.4 Sec) to ST/PL Remote Manual Docking, Stationkeeping, and Rendezvous Time Delay = 0.4 sec).

At contact, the advantage factor of ST/PL over LM/ATM is taken as

$$\frac{d_{LM/ATM}}{d_{ST}} \times \frac{\ddot{X}_{ST}}{\ddot{X}_{LM/ATM}} \times \frac{\ddot{\theta}_{X_{ST}}}{\ddot{\theta}_{x\ LM/ATM}}$$

where

d = distance, docking mechanishm to center of mass

$\ddot{X}$ = maximum possible translational acceleration along X axis.

$\ddot{\theta}_X$ = maximum possible rotational acceleration about X axis.

(Since the OA was fixed in the orbit reference axes, PL motion is not taken into account).

Using the following values,

$$d_{ST} = 6' \quad , \quad d_{LM/ATM} = 15.8'$$

$$\ddot{X}_{ST} = 0.4 \text{ f/s}^2, \quad \ddot{X}_{LM/ATM} = 0.45 \text{ f/s}^2$$

$$\ddot{\theta}_{x_{ST}} = 5 \text{ d/s}^2, \quad \ddot{\theta}_{X_{LM/ATM}} = 5.4 \text{ d/s}^2$$

the advantage factor is

$$\frac{15.8}{6} \times \frac{0.4}{0.45} \times \frac{5}{5.4} = 2.2$$

The contact requirements for ST/PL, as was shown in Ref. 3, were estimated to be 2 times more difficult to meet. Taking the contact requirements into account, the advantage factor becomes

$$(0.5)\,(2.2) = 1.1$$

The upper limit on time delay is then estimated as

$$t_{d_{ST/PL}} = 1.1^{0.5}\ t_{d_{(LM/ATM)/OA}} = 1.05\ (1 \text{ sec})$$

$$= 1.1 \text{ sec}$$

The estimate for time duration is as follows:

$$t_{T_{ST}} = \left(\frac{\ddot{X}_{LM/ATM}}{\ddot{X}_{ST}} \right)^{0.333} t_{T_{LM/ATM}}$$

$$= \left(\frac{0.45}{0.4} \right)^{0.333} t_{T_{LM/ATM}} = 1.04\ t_{T_{LM/ATM}}$$

The estimate for propellant consumption is a function of the mass ratio as follows:

$$\rho_{ST} = (M_{ST}/M_{LM/ATM})\ \rho_{LM/ATM}$$

$$= \left(\frac{490}{876}\right) \rho_{LM/ATM} = 0.56\ \rho_{LM/ATM}$$

Using these factors of 1.04 and 0.56 for extrapolating time duration and propellant respectively, the following estimates (mean values) are made for ST/PL remote manual docking, stationkeeping, and rendezvous:

Docking from R = 50':

time duration = 1.04 (3 min) = 3.1 min
propellant = 0.56 (7030 lb-sec) = 3940 lb-sec
(17.2 lb at I_{sp} = 230)

Stationkeeping at R=150':

propellant rate = 0.56 (197 lb-sec/min)
= 110 lb-sec/min
(0.48 lb/min at I_{sp} = 230)

Rendezvous from R=900', V= 10'/s to R = 120':

time = 1.04 (2.7 min) = 2.8 min
propellant = 0.56 (31800 lb-sec)
= 17800 lb-sec
(78 lb at I_{sp} = 230).

2. Extrapolation from ST/PL Remote Manual to Manual:

The only change is in time delay which goes from 0.4 to 0 second. In the referenced study, the effect on time duration and propellant consumption of increasing the time delay from 0.4 to 1 second was insignificant (although operation at contact was significantly changed); therefore, the estimates for time duration and propellant consumption are estimated to be the same as those just above.

3. Extrapolation from ST/PL Remote Manual to Remote Automatic :

The advantage factors for automatic over manual operation are

(1) At contact: $\frac{\text{6 deg freedom parallel operation}}{\text{2 deg freedom parallel operation}} = 3$

(2) over entire maneuver:

$$\frac{\text{6 deg parallel}}{\text{2 deg parallel}} \times \frac{1}{10}\text{ time} + \frac{\text{2 deg parallel}}{\text{2 deg parallel}} \times \frac{9}{10}\text{ time} = 1.2$$

Based on these advantage factors, the following estimates (mean values) are made:

Docking from R-50' :

time delay, upper limit = $3^{0.5}$ (1.1 sec) = 1.9 sec
time duration = (1/1.2) (3.1 min) = 2.6 min
propellant = (1/1.2) (3940 lb-sec) = 3280 lb sec
(14.3 lb at I_{sp} = 230)

Stationkeeping at R=150':
propellant = (1/1.2) (110 $\frac{\text{lb sec}}{\text{min}}$) = 91.5 $\frac{\text{lb-sec}}{\text{min}}$
(0.40 $\frac{\text{lb}}{\text{min}}$ at I_{sp} = 230)

Rendezvous from R=900', V = 10 '/s to R = 120':

time duration = (1/1.2) (2.8 min) = 2.3 min
propellant = (1/1.2) (17800 lb-sec) = 14800 lb-sec
(64.5 lb at I_{sp} = 230)

4. Extrapolation from ST/PL Remote Automatic to Automatic

In going from remote to nonremote, the time delay goes from 0.4 to 0.second. The parameters for the total maneuver are probably not affected significantly by the change in time delay. Thus the estimates for ST/PL automatic are the same as those for ST/PL remote automatic, as given just above.

5. Summary of Extrapolations

The previous extrapolations that were made are summarized in Table 1. Sloshing propellant effects are not included. It is expected that sloshing propellant would degrade the performance estimates of Table 1.

GZ:ljm

cc:	R. Watson	J. Goodwin	L. Deutsch
	G. Smith	R. McCaffrey	L. Rothenberg
	M. Dandridge	R. Tellalian	E. Eriksen

TABLE 1 Summary of Performance Estimates for Space Tug/Payload Docking, Stationkeeping, and Rendezvous Based on Studies of (LM/ATM)/OA Docking, Stationkeeping, & Rendezvous

SPACE TUG/PAYLOAD

PARAMETER		TYPE OF CONTROL: MANUAL	REMOTE MANUAL (TIME DELAY = 0.4 SEC)	AUTOMATIC	REMOTE AUTOMATIC (TIME DELAY = 0.4 SEC)
Docking From R = 50'	Max time delay (sec)	-	1.1	-	1.9
	Time duration (min).	3.1	3.1	2.6	2.6
	Propellant (lb-sec)	3900 (17 lb)	3900	3300 (14 lb)	3300
Station-keeping At R=150'	Propellant Rate (lb-sec/min)	110 (0.5 lb/min)	110	92 (0.4 lb/min)	92
Rendezvous From R=300' V=10 f/s To R=120'	Time duration (min)	2.8	2.8	2.3	2.3
	Propellant (lb-sec)	17800 (78 lb)	17800	14800 (65 lb)	14800

I_{sp} = 230

EXTRAPOLATED FROM

(LM/ATM)/OA

TYPE OF CONTROL: REMOTE MANUAL (TIME DELAY = 0.4 SEC)
1.0
3.0
7030 (25 lb)
197 (0.7 lb/min)
2.7
31800 (113 lb)

I_{sp} = 281

6.10.5

SUBJECT: STUDY PLAN TO DEMONSTRATE FEASIBILITY OF AUTOMATIC RENDEZVOUS, AUTOMATIC DIRECT DOCKING, AND TV REMOTE RENDEZVOUS AND DOCKING

SUMMARY:

The feasibilities of the following types of rendezvous and docking are to be investigated:

(1) automatic rendezvous,

(2) automatic direct docking, and

(3) TV remote rendezvous and direct docking.

The feasibility of automatic rendezvous is to be determined by the use of a digital computer program which simulates the effects of sensor errors and indirectly sloshing propellant. The trajectory of the Space Tug relative to a payload, the time duration, and the propellant consumption will be computed for nominal and off-nominal initial conditions. Acceptable sensor accuracy will be compared with sensor performance as given by manufacturers.

Automatic direct docking feasibility is to be investigated by the use of a planar analysis digital computer program which will include the effects of sensor errors and sloshing propellant. From nominal and off-nominal initial conditions, the motion of the Space Tug relative to a payload, the time duration, and the propellant consumption will be determined up to the point of contact. Acceptable sensor accuracy will be compared with sensor performance as given by manufacturers.

The feasibility of TV remote rendezvous and docking is to be determined by (1) extrapolation of pilot-in-the-loop studies made at Grumman for other programs & (2) extrapolation from results on the effects of time delay to be obtained using the planar analysis digital computer program for Space Tug/Payload automatic direct docking. Extrapolation (2) involves consideration of pilot reaction time and pilot utilization of TV data as compared to the automatic utilization of the sensed error data. The upper limit on time delay will be compared to the minimum time delay for transmission and formatting as given by manufacturers. Also, the times that the TV picture can be transmitted to ground stations as compared to the times that rendezvous and docking are to occur will be examined.

INTRODUCTION:

It is desired to determine the feasibilities of automatic rendezvous, automatic direct docking, and TV remote rendezvous and docking. A study is required which will result in this determination. The study is restricted to be performed in 3 months beginning June 15, 1973 by one man. Slosh effects are to be included.

The feasibilities of automatic rendezvous and automatic direct docking are to be demonstrated through the operation of two separate digital computer programs.

The approach to be taken is to use existing digital computer programs, because of time and manpower limitations, and to make zero or minimum modification to such programs. An existing digital program without modification will be used to perform the rendezvous analysis. Through a Monte Carlo analysis the sensor and acceleration requirements to achieve successful rendezvous are to be determined. Slosh effects are to be taken into account indirectly by assuming that part of the sensor error is equivalent to attitude control error caused by slosh during translation thrust. The amount of attitude control error due to slosh during translation thrust will be determined during the docking study.

For docking, the existing digital program written by R. Quinn and J. Rietschlin for NASA/MSFC Contract NAS-8-27860 completed in March 1972 by principal investigator K. Speiser will be used with some modification. This program simulates 2 translational motions (forward-backward, up-down) and 1 rotational motion (pitch) for the rigid-body chaser and 1 rotational motion (pitch, fixed characteristics) for the target spacecraft. This program will be modified to include slosh effects.

AUTOMATIC RENDEZVOUS:

It is planned to use the rendezvous digital computer program that J. McNamara used for the EOS proposal. This program is written for use on the IBM 360/165. The run begins after circularization. When the LOS angle from the target to the chaser relative to the orbit reference axes matches a selected value, TPI is performed, with TPI computed for a selected central angle. At 2 selected times after TPI, midcourse maneuvers are performed. For final braking, up to 10 gates may be used. Sensor errors (in range, LOS, range rate, and LOS rate) and acceleration levels may be selected. In one submittal, at least 20 runs may be made for a Monte Carlo analysis, with the statistics of the rendezvous performance being computed automatically.

Time does not permit modification of the program to include slosh effects. (Such inclusion of short-period dynamics would probably increase computer machine time significantly). However, the sensor error (LOS angles), in effect, will be increased beyond its normal value to degrade rendezvous performance in a manner similar to that resulting from slosh. Slosh would tend to increase attitude error during translation burns, resulting in a translational acceleration along a direction offset from that desired. The error in measuring LOS angle results in a computation of thrust direction that is in error. Sensor error and slosh are thus equivalent in the sense that they both result in a translational thrust direction error. (The amount of attitude error resulting from slosh will be determined in the docking study).

Time does not permit the inclusion of short-period dynamics as would result from the modeling of specific control items, i.e., sensor dynamics, control logic, and jet actuation plus effects. (Such inclusion would probably increase computer machine time significantly).

The next higher level of feasibility demonstration that might be required is to demonstrate that sensor hardware (e.g., Scanning Lasar Radar in combination with passive reflectors) can meet the sensor requirements. Such a demonstration is not planned.

Features that are desirable in a digital computer rendezvous program are outlined in Table 2. It is not planned to implement the features described in Table 2.

AUTOMATIC DIRECT DOCKING:

The existing digital computer program for docking permits a planar analysis to be made in the longitudinal and vertical translation axes and about the rotational pitch axis. The target spacecraft has a limit cycle motion (pitch) with fixed characteristics. The docking mechanism can be located off the center of mass on both the chaser and target spacecraft. The thrust is proportional to error. A time delay following the sensing of information can be introduced to simulate signal processing time, pilot reaction time to a display, or transmission time. Errors can be added to the nominal sensed information, and torque failures can be simulated.

After modifying the existing docking program to include slosh effects, the program will be used for a planar analysis (pitch plane). The procedure will be repeated for the yaw plane, by using yaw inertias, etc. The results at contact for the two separate planar analyses will be root-sum-squared. The results for roll will be estimated, based on the pitch and yaw results and the values of the roll parameters - - such as inertias and control torques - - in comparision with the values of the pitch and yaw parameters. Sensor errors, acceleration levels, slosh mass, and time delay are to be varied to determine their effects on docking performance, i.e., conditions at contact and APS impulse consumption.

Features that are desireable in a digital computer docking program are outlined in Table 3. It is not planned to implement these features.

<u>TV REMOTE RENDEZVOUS AND DIRECT DOCKING</u>:

Depending on the autonomy level, rendezvous and docking are performed <u>without ground support</u> (Levels I and II), <u>partly with ground support</u> (Level III, final docking), or <u>totally with ground support</u>. (Level IV). Ground support is interpreted as TV remote control.

It is not possible within the time and manpower limitations, to demonstrate TV Remote Control using an actual pilot. Instead (1) Grumman studies of man-in-the-loop docking (References 2 through 5, as listed in the last section) will be reviewed for possible extrapolation to Space Tug Remote TV Docking and (2) the effects of time delay in the planar analysis that is planned will be determined and applied if possible to Space Tug Remote TV Docking.

<u>SCHEDULE</u>:

The schedule for studies of rendezvous and docking is given in Table 1. Docking is planned first, to obtain results on the effects of slosh in generating attitude error. These results can then be used in the rendezvous study to increase levels of sensor error to simulate the effects of slosh. Primary emphasis in the docking study will be placed on automatic direct docking (sensor errors, acceleration levels, slosh); secondary emphasis will be placed on parameters such as time delay which apply to Remote TV control.

Emphasis in the rendezvous study will be placed on determining the effects of sensor errors and indirectly slosh, since analyses have already been made of acceleration levels.

REFERENCES ON DOCKING:

The following Grumman studies of docking are to be reviewed:

(1) K. Speiser, R. Quinn, J. Reitschlin, et.al. "Study Requirements for Assy. & Docking of Spacecraft in Earth Orbit," Final Report under Contract NAS8-27860, March 1972.

(2) R. Phagan, "Presimulation Report, LM/ATM Docking Feasibility", ARP250-006, dated 6 December 1967.

(3) J. Boudreau, "Apollo Applications Program LM-A/ATM Docking Feasibility Study Summary Report", ARP250-007, dated December 20, 1967.

(4) E. Sommer, G. Steinman," Presimulation Report for LM/ATM Remote Control Simulations," ARP250-008, dated 2 January 1969.

(5) J. Boudreau, "Simulation Report for LM/ATM Remote Control", ARP250-009, dated June 15, 1970.

TABLE I

SCHEDULE FOR INVESTIGATION OF RENDEZVOUS AND DOCKING, SPACE TUG TO PAYLOAD

TASKS	JUNE	JULY	AUG	SEPT
1. Analyze Docking				
1.1 Modify planar digital computer program to include slosh. Checkout modified program.				
1.2 Make runs using modified program. Vary sensor errors, acceleration levels, slosh mass, & time delay.				
1.3 Write up results.				
2. Analyze Rendezvous, beginning after circularization.				
2.1 Make runs using Rendezvous Digital computer program. Vary sensor errors and acceleration levels.				
2.2 Write up results.				

TABLE 2

FEATURES DESIRED IN AN AUTOMATIC RENDEZVOUS PROGRAM, TUG TO PL

1. Requirements for Successful Rendezvous.

2. Space Tug.

2.1 Sensor: R, LOS, and derivatives. Errors. Model of particular radar configuration.

2.2 Command Logic: Circularize at nominal range to target (approximately 100 n.mi.) plus ellipsoid. Acquire and point towards target, narrow band. Continue pointing towards target, narrow band throughout rendezvous. Compute TPI based on sensed information and selected central angle. Perform TPI at nominal position (approximately 40 below, 10 n.mi. behind target) plus ellipsoid. Control continuously in translation and rotation to a range of approximately 1000': translation - - schedule longitudinal and lateral velocity as function of range; rotation - - point towards target using narrow band.

2.3 Control logic, translation and rotation: rate control only -- hysterisis logic; position and rate control-- phase-plane logic.

2.4 Jets: locations, orientations, thrust levels.

2.5 Mass Properties: Structure-- mass, cm location, inertias; slosh mass-- mass, nominal location, motion constraint, inertia.

2.6 Equation of Motion: translation and rotation relative to target - centered orbit reference axes.

2.7 Initial conditions: translation and rotation-- position and velocity.

3. Payload

3.1 Motion: rotation only; nominally coincident with orbit reference axes (X forward, Z along local vertical down); variations about nominal are limit cycles about X, Y, Z axes; motion properties remain constant, no dynamics.

3.2 Passive reflectors: package location and orientation, geometry of reflector locations, size and reflection characteristics of each reflector.

3.3 Initial Conditions: attitude and angular velocity

TABLE 2

(CONTINUED)

4. Output of Study

4.1 Single run.: Performance-- translation, rotation, success or failure, APS impulse consumption.

4.2 Effects of (1) sensor accuracy, (2) chaser acceleration -- translation and rotation, (3) slosh.

4.3 Statistics of many runs.

TABLE 3

FEATURES DESIRED IN AUTOMATIC DIRECT DOCKING,

TUG TO PL

1. Space Tug

1.1 Sensor: Range R, LOS attitude (ψ, θ, ϕ) and derivatives. Errors. FOV. Modeling of specific radar configuration.

1.2 Command Logic: Translation-- longitudal velocity schedule as function of range. Lateral error zero. Rotation-- for R less than 1000' but more than approximately 50', point towards PL; for R$<$50', align attitude with PL attitude.

1.3 Control Logic, translation and rotation: rate control only -- hysterisis logic; position and rate control-- phase-plane logic.

1.4 Jets: locations, orientations, thrust level.

1.5 Mass Properties: Structure-- mass, cm location, inertias; slosh mass-- mass, nominal location, motion constraint, inertia.

1.6 Docking Mechanism: location, orientation.

1.7 Equations of Motion: translation and rotation relative to target centered orbit reference axes.

1.8 Initial Conditions, translation and rotation: position and velocity.

2. Payload

2.1 Motion: rotation only; nominally coincident with orbit reference axes; variations about nominal are limit cycles about X, Y, Z axes; motion properties remain constant.

2.2 Passive reflectors: package location and orientation, geometry of reflector locations, size and reflection characteristics of each reflector.

2.3 Docking Mechanism: contact requirements; location and orientation.

2.4 Initial Conditions: rotation-- attitude and angular velocity.

TABLE 3

(CONTINUED)

3. Output of Study

3.1 Single run: performance-- translation, rotation, success or failure, APS impulse consumption.

3.2 Effects of (1) sensor accuracy, (2) chaser acceleration -- translation and rotation, (3) Slosh, (4) docking mechanism location-- Tug, PL.

3.3 Statistics of many runs.